Design and analysis of power converter for a photovoltaic system.

ELECTRICAL ENGINERRING POWER ELECTRONIC

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Introduction

Photovoltaic system in general referred as PV system, PV system technology can produce the generation of electricity in reliable way, and using solar energy can solve more than one problem, like, cutting down on carbon emissions and dependence on fuels. This is the way to solve the energy crisis! The Solar energy is the most sought after energy source in the world, this is known as photovoltaic process. The name photovoltaic is from the word "photo" which it means light and "voltaic" is production of electrical energy.[١] The arrangement of the PV cells in the system which depends on, therefore a DC source of electricity produced.

In this project, one of the main characteristics of the solar panel system it will be taken into consideration, which is the level of insulation. It is defined as an amount of radiation reaching the solar panel surface. However, DC/DC converter is built beside controlled source voltage electrical machinery. The main purpose of DC/DC converter is to step down the voltage which known as buck converter.

Solar chargers are simple and portable ready to use devices. This preliminary report explains a photovoltaic charger.The electrical energy produced from the PV cells will be stored in a rechargeable battery with a charge controller will regulate the charging process. A voltage regulator will need to construct to regulate a ٥V DC power supply for the charging of handheld devices like mobile phones and tablets.

Aim

The aim of this project is to understand how solar panels converting light into energy, also to gain knowledge about collecting energy and charge a battery from sun by using solar panels. However it can be further be broken down into as follow:

١. Understanding operation of converters in PV application.

٢. Underline the different essential features required for converters used in PV application.

٣. Understanding how to regulate the voltage from the solar panel to have constant voltage to charge batteries by using buck converter.

٤. Design and analyse a circuit for power converter which solar panel charge a mobile battery alone with rechargeable batteries.

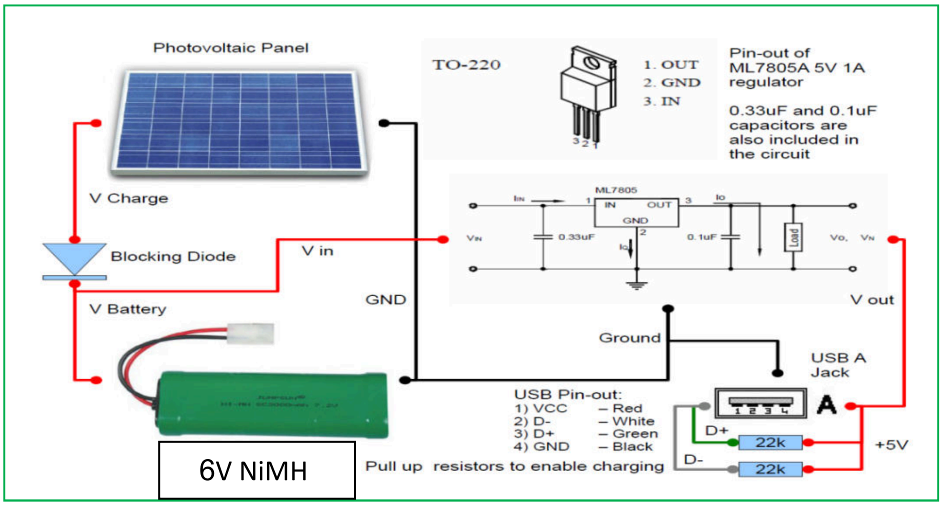

Figure١. PV based ,battery charger using voltage converter.[٢]

Objective

- Developing and assimilate buck converter and LT١٠٧٤[٣]with basic solar charger.
- Redesigning and testing the project on multisim.
- Design the circuit on breadboard for testing.
- Final part is to building the DC-DC circuit on PCB.

Deliverable

The deliverable for this project is the main output of the project also describe as follows:

- To be able to produce a power converter for PV system.
- To be able to produce a formal report showing an in-depth understanding of power converter for photovoltaic application also analysis, testing and building.

Scope of work

According to the scope of this project, PV power converter to be modelled will include the following primary components:

- PV module
- Step-down DC-DC Buck Converter

The project also comprehend simulation and analysis of the power converter on multisim, ways of diminishing them and to research about the effect of the number of pulse the converter is operating at so as to meet the aims and objectives.

Three step approximation for this project

١. How much energy the internal battery can store?
٢. How much energy a solar panel can generate over period?
٣. How much energy will the mobile charger require?

Technical background and context

In this section of the report shows the existing knowledge about photovoltaic converters in general also the components related in converting solar energy to electrical energy.

Overview of the PV System Model

The block diagram of the PV system to be modelled is shown in the figure below:

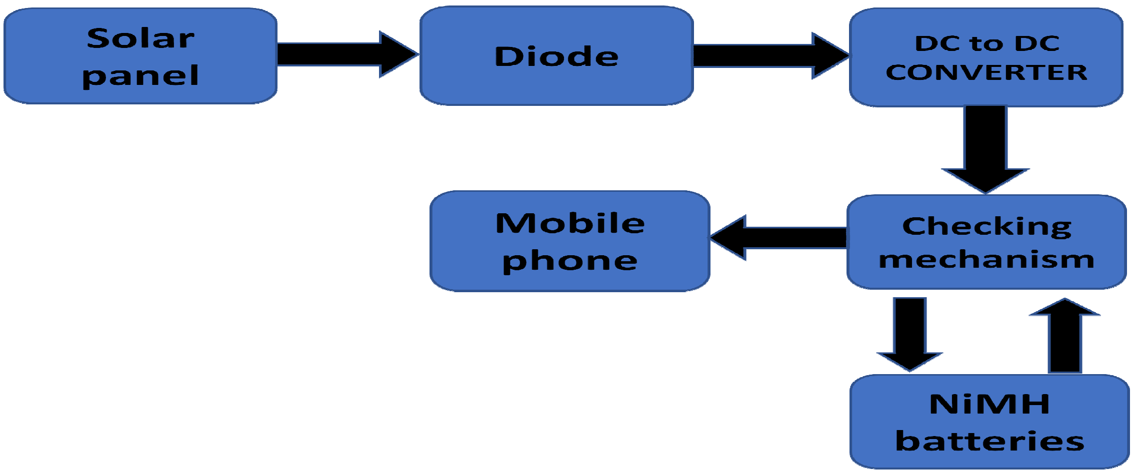

Figure ٢.block diagram of the PV system

The solar panel module will lead to production of a variable DC voltage, Vpv which will be fed to the DC-DC buck converter.

Solar panel (PV) Cell

A photovoltaic cell (PV cell)[٤] is a specialized semiconductor diode that converts visible light into DC current by a process which is called photovoltaic effect moreover The conversion of solar radiation into an electron current, takes place in the photovoltaic cell

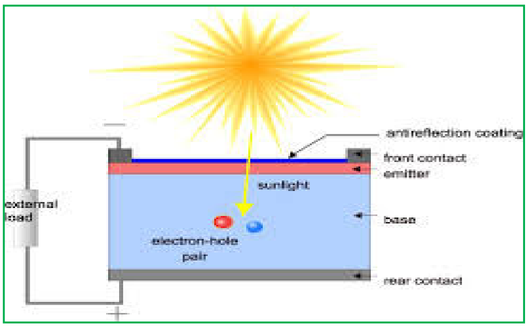

Figure ٣.sun energy converted electricity using PV cell

Photovoltaic module

PV module is a grouped number solar cell which they are arranged in series or parallel in order to meet the energy requirements. The purpose of arranging the cells in parallel or series are increasing current and voltage. A collection of solar cells called "solar panels" (Solar Array) Small solar cells spread over a large area can work together and produce enough power to generate electricity.[٥]

The output of a solar panel (PV) normally stated in watts, and the wattage is determined by multiplying the rated voltage by the rated amperage as shown in equation١.

$$Power(W) = Amps(I) \times Voltage(V) \qquad (١)$$

The power (W) of the solar panel will determine how quickly the internal battery is charged. The speed at which phone battery is charged from the batteries will not change.

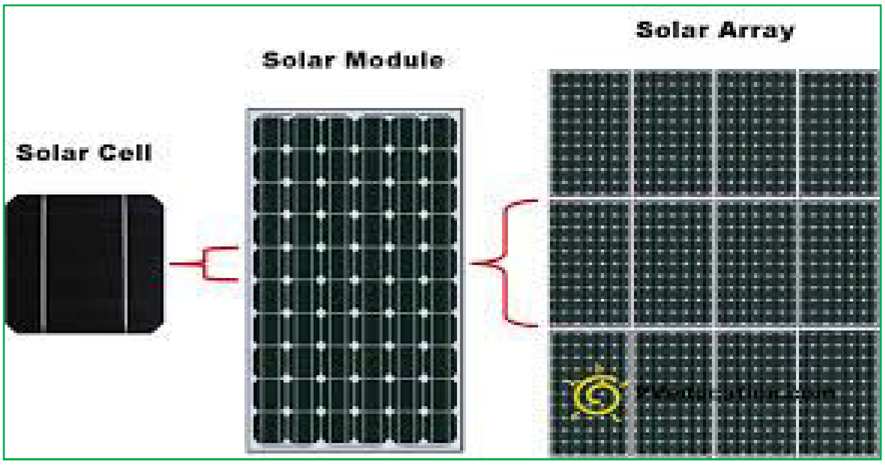

Figure ٤.Mono crystalline type solar panel[٦]

Photovoltaic modeling

Based on circuit perspective and these deductions, a PV cell can be designed as an equivalent circuit diagram shown below: where IL is the current generated from the result of PV effect and Rp.

If the DC voltage produced is high enough, it will be a significant reduction in the current of the PV cell which will comport similar to a diode on a graphical representation of a diode’s characteristic.

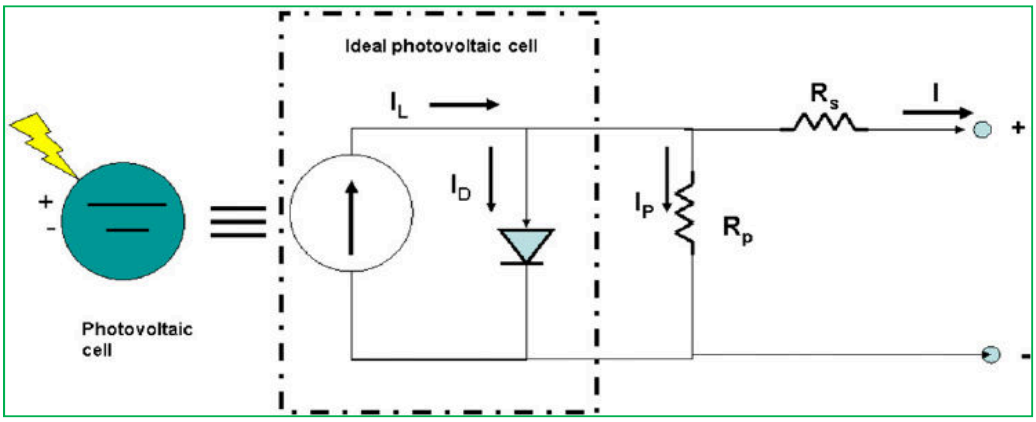

Figure ٥.equivalent circuit diagram of a PV cells[٧]

Parameters of the ideal PV Cell and including the series resistance, Rs

From mathematically point of view, the I-V characteristics of an ideal PV cell of the figure above can be explained by the following equations[٨]:

$$I = IL - Io(e^{\frac{qv}{mkT}} - ١) \qquad (٢)$$

Where:

IO= Reserve saturation current of the diode

m= Ideality factor of the diode

T= PV cell operating temperature

K= Boltzmann's constant (١,٣٨ x $١٠^{-١٩}$ $m^{٢}$kg $s^{-٢}k^{-١}$)

q = electron charge (١,٦٠ x$١٠^{-١٩}$ –c)

m is PV cell which can be considered by at least the diode ideality factor and the open circuit voltage, Voc and the short circuit current, Isc.

For the same irradiance with operating temperature condition of the p-n junction:

Isc = Is(for V)= I= ٠: (٣)

V = Voc = $\frac{mkT}{q}$(١+$\frac{Isc}{IO}$) for l= ٠; (٤)

Isc and Voc are the highest current value also the highest voltage value at the output terminals produced by the cell.

I, V characteristics of the PV cell can be represented by the given equation:

$$ISC = IL - IO\left(e^{\frac{q(v+RsI)}{mkT}} - ١\right) \qquad (٥)$$

Graphical (I, V) and (P, V) characteristic of PV cells

Solar Cell (I, V) Characteristic Curves show the current and voltage characteristics of a photovoltaic (P, V) cell.

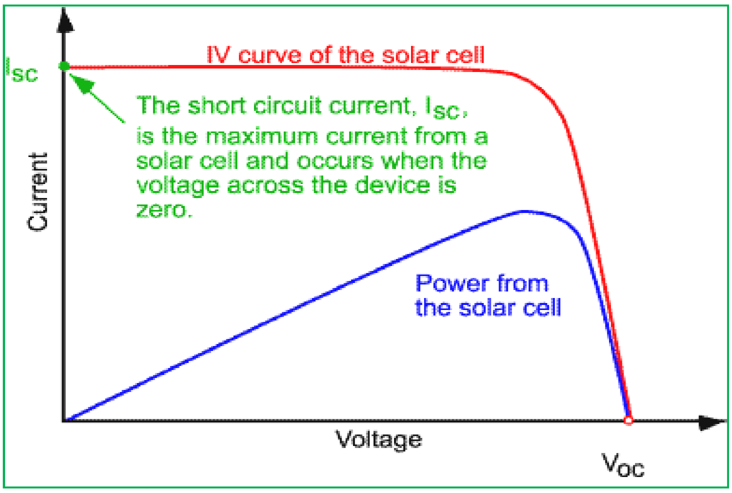

Figure6. (I,V) and (P,V)curve of a PV cell

Maximum Power Point Tracking

A maximum power point (MPPT) algorithm is used for transferring maximum power from the PV module to the load and extracting the maximum power from the solar panel. MPPT method is the key factor for optimizing the use of solar panels. Therefore this technique is useful to maintain the PV array of operating at its MPP.

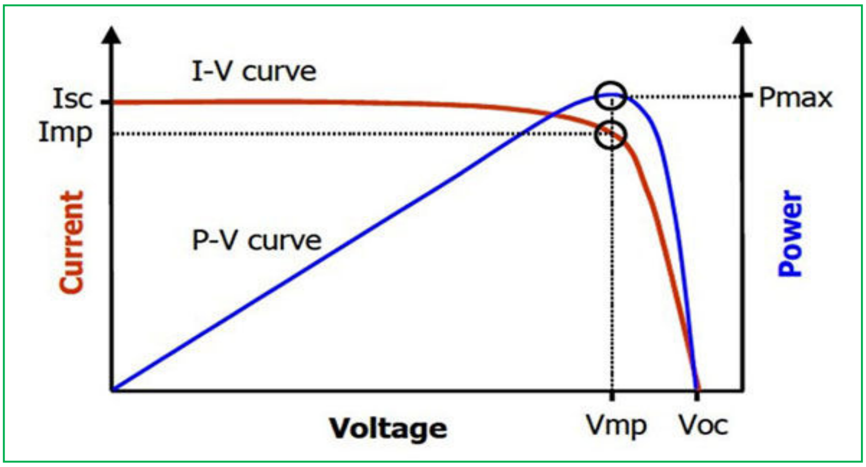

Figure 7.MPPT

A dc to dc converter which is interface between load and module, serve the purpose of transferring maximum power from PV module to the load.

Solar panels efficiency

“The efficiency defined as the ratio of energy output from the solar cell to input energy from the sun, Efficiency is the most commonly used parameter to compare the performance of one solar cell to another.

In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. Therefore, conditions under which efficiency is measured must carefully measure in order to compare the performance of one device to another” [١١]

The efficiency of a solar cell is determined as the result of incident power, which converted to electricity and defined as equation ٦ and ٧.

$$Pmax = VocIscFF \qquad (٦)$$

$$\eta = \frac{VocIscFF}{Pin} \qquad (٧)$$

Where:
V_{oc} is the open-circuit voltage;
I_{sc} is the short-circuit current;
FF is the fill factor and
η is the efficiency.

The input power for efficiency calculations is ١ kW/m^{٢} [١٢]

DC-DC Converter

DC-DC converters are used in applications where an average output voltage is required, however, this is power electronic circuit which converts a DC voltage into a different DC voltage and provides a regulated output.

A DC-DC (step down) converter is usually called buck converter, which used to match the impedance of the load to the solar panel whose output voltage is smaller than the input voltage and output current is larger than the input current, by changing the duty cycle, therefore. The load variation in turn causes a change in the operation point (current and voltage characteristics) of the panel.

Switch mode DC-DC converters operate by storing the input energy from the panel in the capacitor temporarily and then releasing stored energy to the buck converter output at a different voltage and current.

Buck converter parameters

There are three different parameters which need to be set in general, in order to implement an efficient design of a buck converter as follows:

١. Range of input voltage (minimum and maximum Vin)
٢. Output voltage (Vout)
٣. Output current (Iout (max))

Buck converter circuit diagram

For this preliminary report a buck converter or voltage regulator is also called a step down regulator used. The topology is a classic positive "buck" configuration, moreover, this device is used as a positive-to-negative converter and the output voltage is lower than the input voltage. A diode is connected in parallel with the input voltage source, a capacitor, and the load, which represents output voltage. A switch is connected between the input voltage source and the diode and an inductor is connected between the diode and the capacitor.

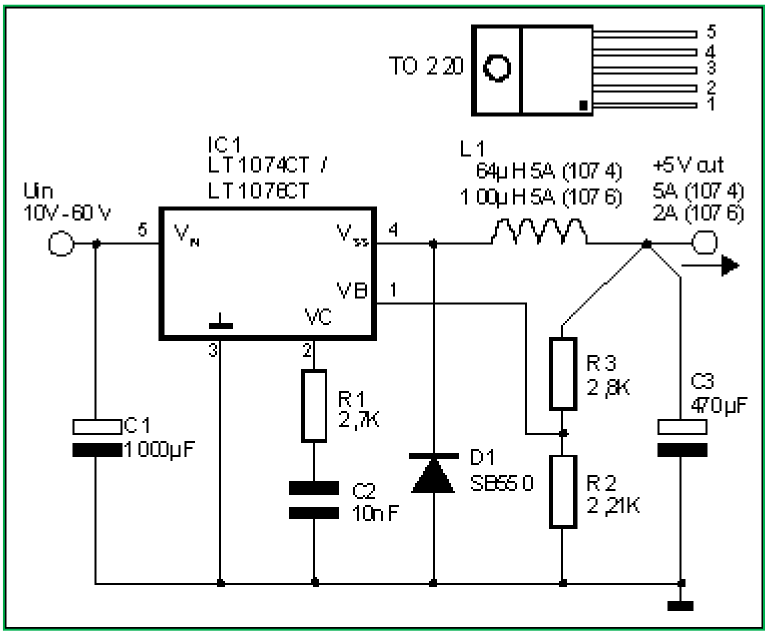

Figure 8.Buck convreter circuit diagram with TO 220

The circuit respond nearly instantaneously to input voltage and makes loop gain independent of input voltage. The LT١٠٧٤ uses a true analog multiplier in the feedback loop. The switch output is specified to swing from ٨V to ٤٠V below ground, allowing the LT١٠٧٤ to drive a tapped inductor in the buck mode with output currents up to ٥A.

(LT١٠٧٤) PIN description

A ٥pin lead plastic with input voltage range of ٨v to ٣٠v, with ٥A output at ٥V tapped-inductor Buck converter.

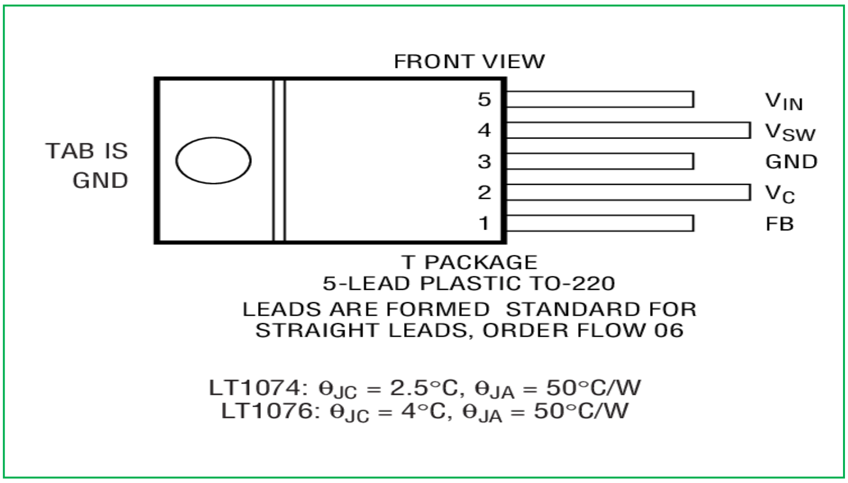

Figure 9.Step Dawn switching regulator

VIN PIN

"V_{IN} pin at full switch current of ٥A, the switching transients at the regulator input can get very large, both the supply voltage for internal control circuitry and one end of the high current switch. Input current on the V_{IN} Pin in shutdown mode is the sum of actual supply current".[١٣]

Ground Pin

The ground pin must be connected directly to the proper output node. To prevent high currents flow in this path from happening and ensure good load regulation,

Feedback Pin

the feedback pin is the inverting input of an error amplifier which controls the regulator output by adjusting duty cycle, the Feedback Pin is used to downshift the oscillator frequency when the regulator output voltage is low also the no inverting input is internally connected to a trimmed reference.

SHUTDOWN PIN

The shutdown pin is used a general purpose on/off control of the regulator output or for micro power shutdown, under voltage lockout, soft-start, delayed start.

Investigation and Observation of buck converter:

The Buck Converter is used in switching-mode power supply circuits where the DC output voltage needs to be lower than the DC input voltage.

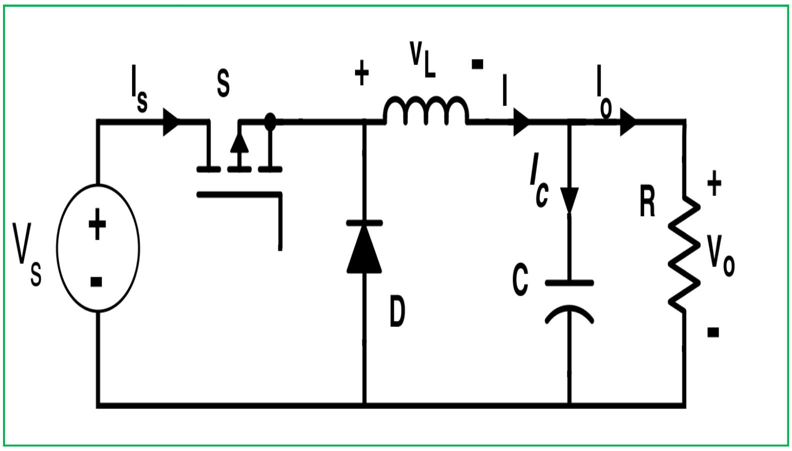

Figure 10.Buck converter ON and OFF

Buck converters provide regulated output by using an inductor, which the output value is controlled by the ON and OFF periods of the switch, moreover the switching transistor between the input and output of the Buck Converter continually switches ON and OFF at high frequency. And continuous output obtained.

Switched ON period

During the time that the switch is ON, current flows from the input, through the switch, through the inductor L, to the output therefore charge on capacitor builds up gradually and current in the inductor increases and the inductor stores energy. The diode does not have any action and act as reverse biased because of a large positive voltage on D cathode

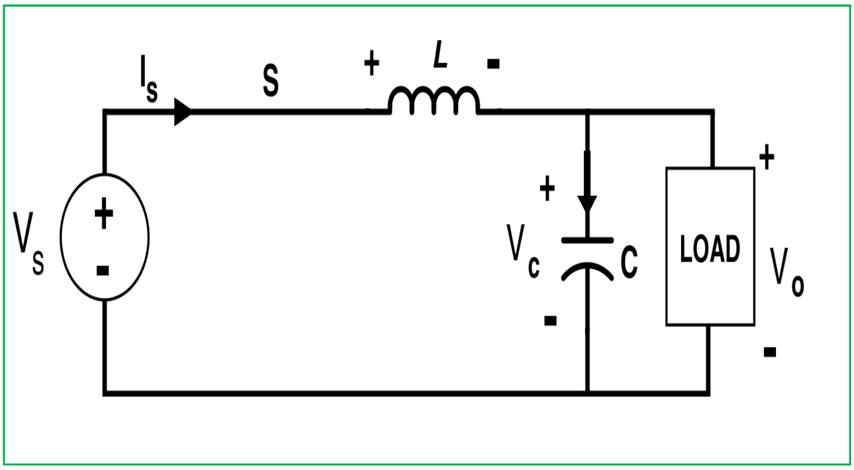

Figure 11.Switch ON Period

applying the Kirchhoff's voltage law, during the ON period, however an inductor resists a change in current and capacitor resists a change of a voltage. ON time for a buck converter in continuous mode calculated as;

$$Ton = \frac{Vout+Vd}{Vin*f} \qquad (٨)$$

Where;

Vd = Diode forward voltage

f = Switching frequency

Switched OFF period

When the switch is OFF, the energy already stored in around L is released back into the circuit. Diode is acting as short circuit therefore now forward biased. , the charge stored in C becomes the source of current and this process will keep current flowing through the load until the next ON period begins.

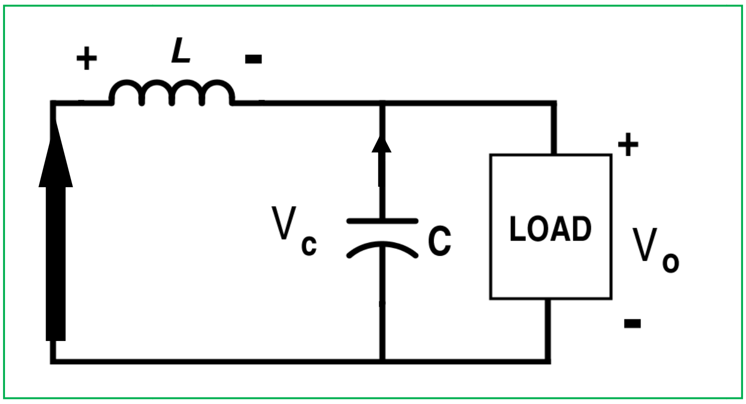

Figure 12.Switch OFF period

The voltage across the inductor is now in reverse polarity to the voltage across L during the ON period, and sufficient stored energy is available, the inductor supplies the output current and the magnetic field in the inductor decreases the counter e.m.f. from L now causes the current to flow around the circuit via the load.

Buck Converter Observation

To process the observation and calculation this preliminary project, Electronic test equipment provided, in order to build the circuit and create signals to capture responses.

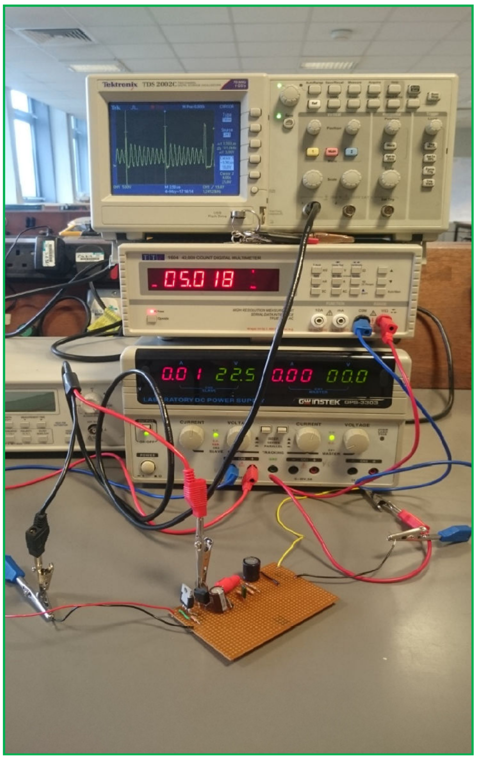

Figure 13.testing Buck converter, project room.

Duty cycle calculation

A duty cycle represents the fraction of one period of time in which a signal is active. The periodic time (given the symbol T), in seconds or milliseconds etc, which the time takes to complete an on-and-off cycle, Duty cycle is commonly expressed as a ratio of output voltage to input voltage or percentage, Like Pulse Width **(PW)** which is the length of activation between the rising and falling edges of a single pulse.

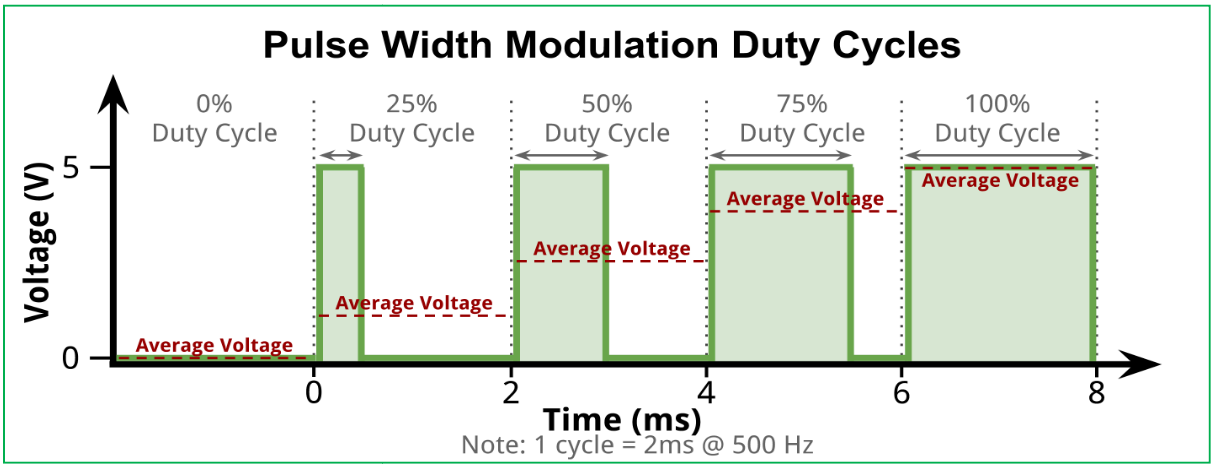

Figure 14.Duty cycle , PWM and Average voltage

Duty cycle cannot be measured directly but it is calculated value, to calculate a signal's duty cycle, we need to know the signal's pulse width and time duration.

To calculate duty cycle percentage;

$$D = \frac{PW}{T} \times \text{١٠٠٪} \qquad (\text{٩})$$

To calculate duty cycle ratio;

$$D = \frac{PW}{T} \qquad (\text{١٠})$$

Where;

D = Duty Cycle

PW = pulse width

T = total period of signal time .

$$f = \frac{\text{١}}{\Delta T} \qquad (\text{١١})$$

$$\Delta T = \frac{١}{f} \qquad (١٢)$$

The buck converter analyzed and the variation of wave form ripple captured on the oscilloscope, hens there are more than one frequency, by selecting two high pulls on the oscilloscope screen and reading high frequency with a ΔT.

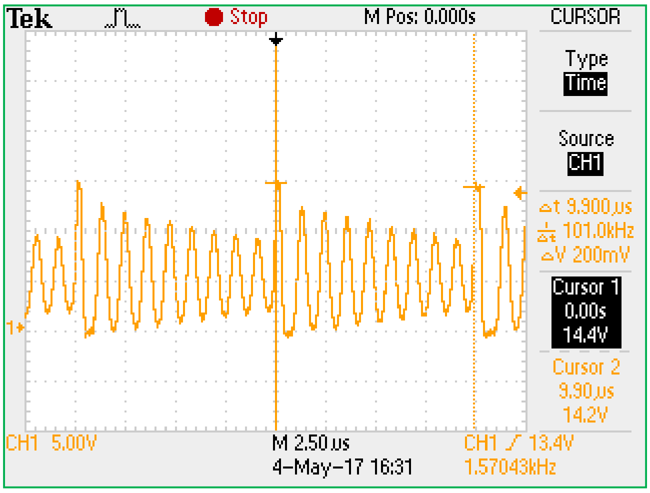

Figure 15.Delta T and Frequency reading on oscilloscope

Testing the buck converter curried out and the wave form captured on the oscilloscope as shown in figure ١٦.

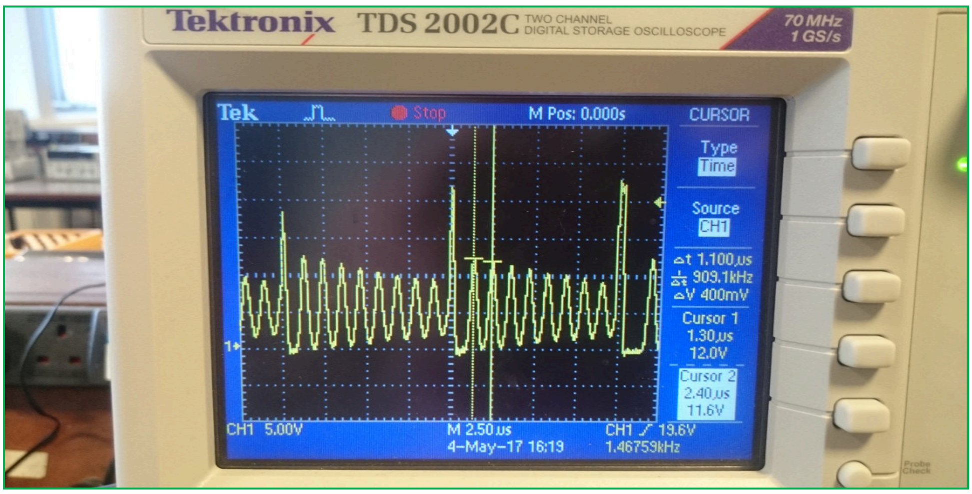

Figure 16.Buck converter waveform with 5v output

Time and Frequency observation of the DC to DC buck converter by varying the Input voltage from ٥ volt to a maximum of ٣٠ volt rang of different duty cycle between the polls parameter shown in the table below:

Input voltage	ΔT
٢٩,٨ V	٩٠٩,١ KHZ
٢٠ V	٩٠٩,١ KHZ
١٥ V	٩٠٩,١ KHZ
١٠ V	٩٠٩,١ KHZ
٧ V	٩٠٩,١ KHZ
٥ V	٧٦٩,٢ KHZ

Table 1.Delta Time observed with deferent value of input voltage

The reasons for not increasing the input voltage above ٢٩,٨v is that, the inductor coil and diode value are not as exact is the circuit drawing given for this project .although the Buck converter circuit function but for better result in efficiency and duty cycle therefore more accurate component required .

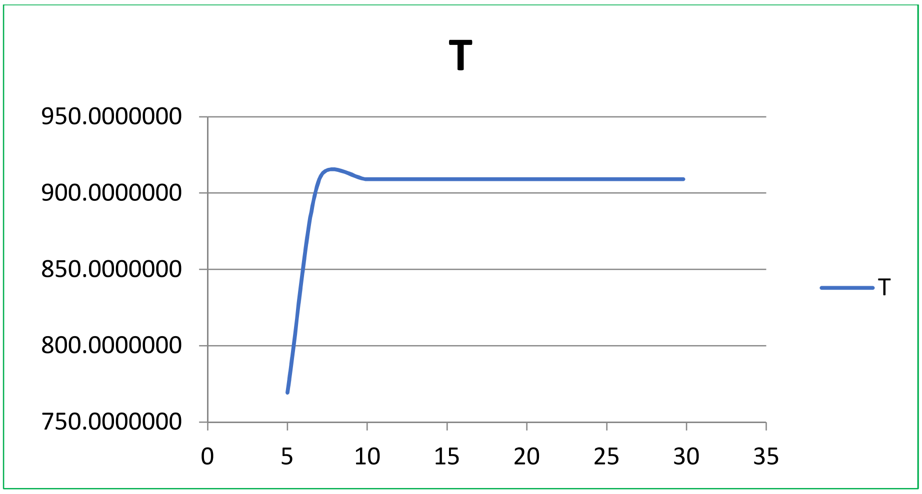

Figure 17.Delta T along Y-axis

Input voltage	f
٢٩,٨ V	١٠٠ KHZ
٢٠ V	١٠١ KHZ
١٥ V	١٠١ KHZ
١٠ V	١٠١ KHZ
٧ V	١٠٠ KHZ
٥ V	٩٢,٥٩ KHZ

Table ٢.Friquency measurement.

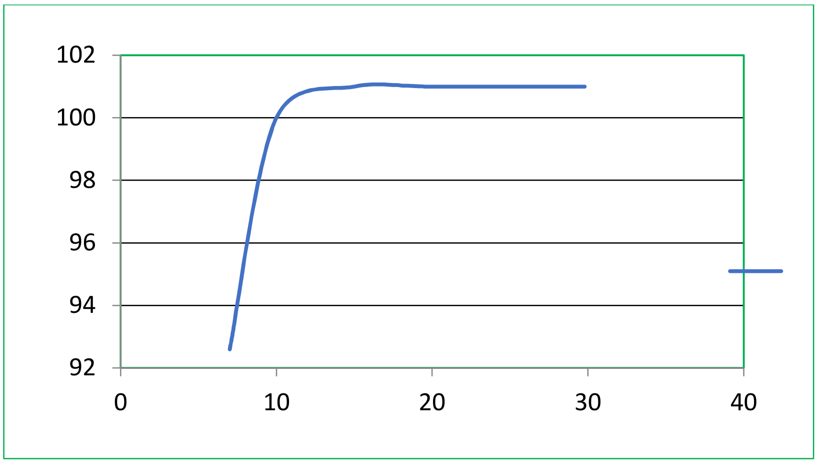

Figure ١٨.Friquency plot on the graph

Output voltage observation:

After varying the buck converter with input voltage between ٠V to ٣٠V, the output voltage increased at ٥v noticeably, however when the input voltage increased to ٨v, the Vout reached to ٥ volt observed as follow.

Input voltage	Output voltage
٠ V	٠,٠٠٢٢ V
١ V	٠,٠٠٣٣ V
٢,٥ V	٠,١٠٦٢ V
٥ V	٣,٥٨٦٦ V
٦ V	٤,٢١٧ V
٧ V	٤,٨٠٦ V
٨,١ V	٥,٠١١ V
١٠ V	٥,٠١٢ V

١٥,١ V	٥,٠١٤ V
٢٢,٥ V	٥,٠١٧ V
٣٠ V	٥,٠١٨ V

Table ٣.Output Voltage measurement

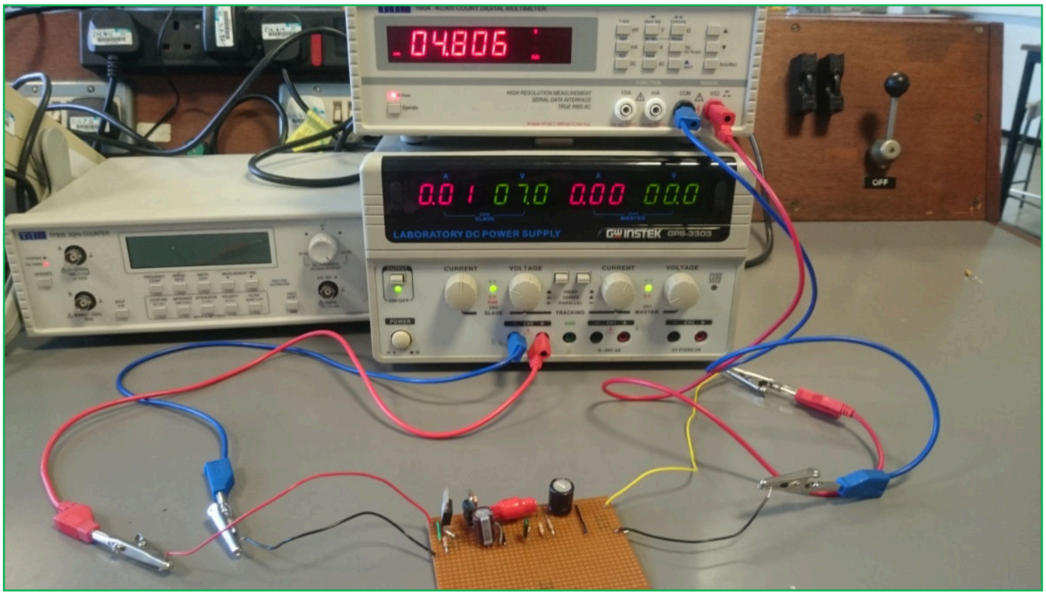

Figure 19.output voltage equipment measurment

The equipment used for this project to measure the buck converter output voltage is provided using digital millimeter and DC power supply the output respond is as expected but only when the input voltage ٧,٥v

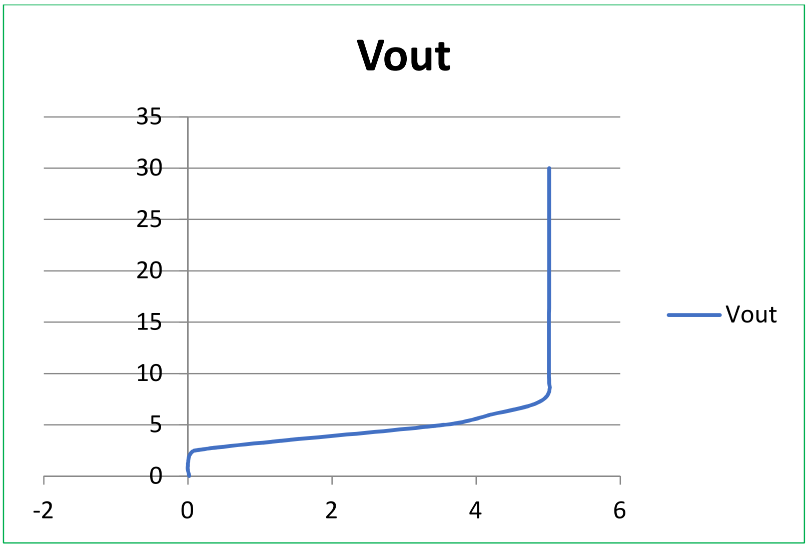

Figure ٢٠.Buck Converter voltage measurement on graph

Conclusion

- Solar panels chargers are as good as power supplies.
- Solar charger circuits need voltage regulators to charge the batteries at constant voltage.
- Voltage regulated due to variation
- LT١٠٧٤ solves the problem by regulating the voltage step down
- The battery charging process should stop once it is fully charged.
- Not achieved the charger circuit will not be combining with a voltage and current regulator to not be used for NiMH battery and mobile phone as a charger.

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- https://www.rroij.com/open-access/dc-to-dc-converter-in-maximum-power-pointtracker.php?aid=٤٢٩٨٤
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