Design of Dc-Dc Converter with Maximum Power Point Tracker Using Pulse Generating (555 Timers) Circuit for Photovoltaic Module

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Abstract— due to the decline in power of photovoltaic module as a result of changes in irradiation which affect the photovoltaic module performance, the design and implementation of DC-DC boost converter operating in continuous conduction mode with a Maximum power point tracker using a Microcontroller connecting a 555 timer circuit to generate Pulse Width Modulation (PWM) signal to established a constant output voltage was proposed. The system is a close loop system and continuously measure samples of current and voltage from output of photovoltaic module and reference voltage at the load (lead base light, 24V) to obtain instantaneous power. Base on this, the 555 timer circuit (pulse generator) constantly takes in DC voltage through a current source to control the duty cycle of the DC-DC boost converter. Also PSIM and Pspice software were used to simulate DC-DC boost converter and compare simulation results with the practical operation of the design system.

Index Terms— DC-DC boost converter, Maximum power point tracker, Photovoltaic module, Pspice; Pulse width modulation, Microcontroller.

1 INTRODUCTION:

According to [1] DC-DC converters are widely used in regulated switch mode DC power supplies. The input of these converters is unregulated DC voltage, which is obtained by PV array and therefore will be fluctuated due to change in radiation and temperature. Renewable energy is growing rapidly and it is becoming significant in our world today and in the future to come. Photovoltaic (PV) is one of the most important area in the field of renewable energy and has attracted lots of research. In the past years, PV power generation systems have attracted attention due to the energy crisis and environment pollution. Photovoltaic power generation systems can mitigate effectively environmental issues such as the green house effect and pollution [2]. One major problem with photovoltaic module is that the electrical output power depends on the weather condition that is; the output is changing with a change in weather condition which makes photovoltaic module nonlinear power source. Due to the weather condition mention above and other factors listed below in (2.0), the maximum power point of the photovoltaic module as describe below in figure (5, 6) will shift away from the maximum operating point of the module. Base on this result a maximum power point tracker (MPPT) employing DC-DC converter is develop and used to maintain the maximum power point (MPP) of the module. Many MPPT methods have been develop over the years to achieve the maximum power point of the PV module in different papers; examples are the incremental conductance (IC) method [3], perturbation and observe (P&O) method [2], the fuzzy logic [2], microcontroller base method [4] [5] etc. In this paper it is intended to design an easy to use DC-DC converter (boost converter) with maximum power point tracker for photovoltaic module to control the photovoltaic interface so that the operating point of the load and photovoltaic module meet at the maximum power point no matter the electrical power output of the module. The converter will be connected between the photovoltaic module and the load (a led based light with nominal voltage of 24V) without a battery so as to supply the load with 24V at all time. The design will be used by both skilled and unskilled people, and will be both portable and practical in the field of engineering and renewable energy. The method in this paper is a feedback microcontroller based MPPT control method with a boost converter operating in continuous conduction mode. This characteristic of continuous input current makes the boost converter suitable as photovoltaic interface. The block diagram of the adopted method is described below in figure 3. The component used in the propose control design is a pulse generator

(555timer circuit) to change the duty cycle, a microcontroller and a gate. In the project we will also design and implement the DC-DC converter (boost converter).

2 OVERVIEW OF PHOTOVOLTAIC ARRAY:

Photovoltaic cell also known as solar cell is used to convert energy from the sun directly into electrical energy without any form of rotational parts. Photovoltaic cells represent the basic fundamental power conversion unit of photovoltaic system. These cells are made from semiconductors and like any other solid-state electronic devices e.g diode, transistors and integrated circuit, they have similar behavior. Photovoltaic cells are usually arranged into modules and array when applied practically [6]. There are different types of photovoltaic cells available on the market and yet different other types of cells are under development e.g. dye-sensitized Nand-crystalline cells. The reason for different types of photovoltaic cell, materials and structure is to extract maximum power from the cell and to maintain cost to a minimum. According to [6] efficiency above 30% have been achieved in laboratory and efficiency of practical application is usually less than half of this value. Crystalline silicon technology is well established and its cell is more expensive but still controls a major part of the photovoltaic market with efficiency approaching 18%. Other types of photovoltaic cells like amorphous thin films are less expensive but with disadvantage of poor efficiency. There are several factors that affect the electrical performance of a photovoltaic module from operating at optimal operating point. These factors are (1) Sunlight intensity/irradiation (2) Cell temperature (3) Load resistance and (4) Shading and the use of photovoltaic array and maximum power point tracker (MPPT) to curb these challenges are developing rapidly.

3 OVERVIEW OF DC-DC CONVERTER:

DC-DC conversion technology is a major subject area in the field of power electronic, power engineering and drives. The conversion methods have application in industries such as telecommunications, automotive, renewable energy, research etc and have gone under series of developmental stages for more than sixty (60 years). This conversion technique is widely adopted in industrial application and computer hardware circuits. The ideas of DC-DC conversion technique and development have been on for over 80 years. The simplest DC-DC conversion technology is a voltage divider, potentiometer and so on. But the effect of these simple conversion techniques resulted in poor efficiency due to fact that transfer output voltage is lower than the input voltage. According to [7], there have been more than 500 prototypes of DC –DC converter developed for more than 60 years. All new topology and presently existing DC-DC converters were design to meet some sort of industrial or commercial applications. They are usually called by their function, for example, Buck converter, boost converter, buck-boost converter and zero-switching (ZCS) and zero voltage switching (ZVS) converters which are used to reduce, increase voltage ….respectively. DC-DC converters (e.g. boost, buck, buck boost, etc) are also implemented with other devices as maximum power point trackers (MPPT) for photovoltaic module, for example in [8] a real time MPPT employing a DC-DC boost converter operating in conduction mode is used. It also includes a passive non dissipative turn on turn off snubber in order to achieve high efficiency and to reduce EMI level due to soft switching.

3.1BOOSTCONVERTER ANALYSIS:

The designed DC-DC boost converter is connected between the photovoltaic module and the load so as to enable the module operates at maximum power at all time. Boost converter is made of up four elements as shown below in figure 1, they include the inductance, diode, capacitor and M0SFET. As the name of the converter implies, it steps up the input voltage which makes the output voltage greater than the input voltage. The converter is control through the MOSFET which act as a switch. The ON and OFF of the switch (MOSFET) controls the output voltage by changing the voltage of the inductance so as to enable the photovoltaic module power the load at maximum voltage. The operation of the converter is analyzed in different operating condition. The operation of the converter is analysis in continuous conduction mode.

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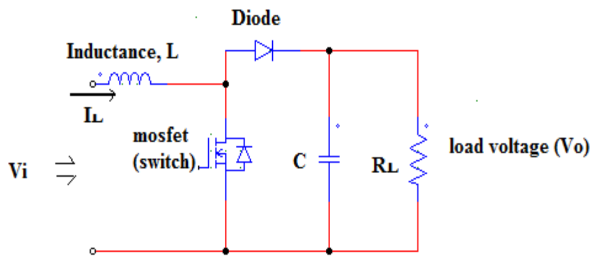

Figure 1 Step up dc-dc converter [9].

3.11 CONTINUOUS CONDUCTION MODE (CCM):

In continuous conduction mode the inductance current flows continuous [$i_L(t) > 0$] as illustrated with the steady state waveform below in figure 2.

The time integral of the inductor voltage over one time period must be zero in steady state.

$$V_d t_{on} + (V_d - V_o) t_{off} = 0 \qquad (1)$$

When the switch (MOSFET) is turned ON, the diode is reverse biased, thus disconnecting the output stage. The input then delivers energy to the inductor. When the switch (MOSFET) is turned OFF, the output stage is now reconnected and receives energy from the inductor as well from the input. In the steady state analysis presented here, the output filter capacitor is assumed to be very large to ensure a constant output voltage $V_o(t) \sim V_o$ [9].

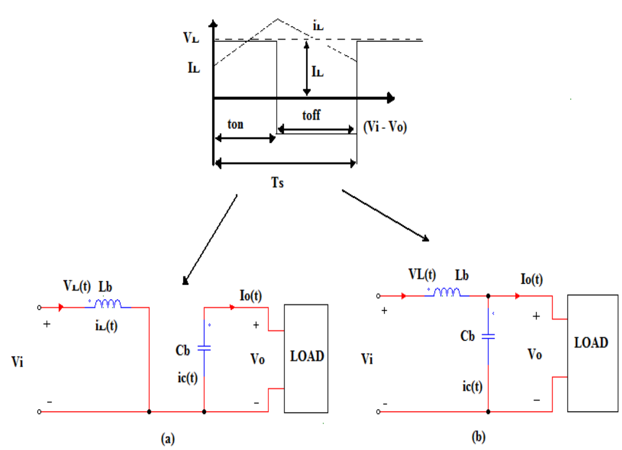

Figure 2.0 Equivalent Circuit for boost converter in continuous conduction mode (CCM); (a) switch ON; (b) switch OFF.

Dividing both sides of equation (1) by T_s and rearranging terms yield the transfer function of the converter. See transfer function of the converter in equation (2)

$$\frac{Vo}{Vd} = \frac{Ts}{ton} = \frac{1}{1-D} \qquad (2)\ [9]$$

And equation (2) confirms that the output voltage is greater than the input.

Assuming a losses circuit, $P_d = P_o$,

Therefore $V_d I_d = V_o I_o$

And

$$\frac{Io}{Id} = (1 - D) \qquad (3)[9]$$

4 MAXIMUM POWER POINT TRACKER (MPPT):

A maximum power point tracker is a high-efficiency DC-DC converter, which functions as an optimal electrical load for photovoltaic cell, most commonly used for a solar panel or array and converts the power to a voltage or current level which is more suitable to whatever load the system is design to drive. PV cells have a single operating point where the values of current and voltage result in a maximum power output for the cell [10]. Maximum power point tracker (MPPT) is basically an electronic system that controls the duty circuit of the converter to enable the photovoltaic module operate at maximum operating power at all condition and not some sort of mechanical tracking system that physically rotate the photovoltaic modules to face sunlight directly. The advantages of MPPT regulators are greatest during cloudy or hazy days, cold weather or when the battery is deeply discharged. There are different types of maximum power point tracker methods developed over the years and they are listed below as follows (1) Perturb and observe method, (2)Incremental conductance method, (3) Artificial neutral network method, (4) Fuzzy logic method, (5) Peak power point method, (6) Open circuit voltage method, and (7) Temperature method etc. The MPPT plays a very significant role because without the MPPT the desire output electrical power will not be achieve with changing weather conditions. The adopted topology for the MPPT design will comprise four parts, namely Microcontroller, pulse generator (555 Timer Circuit) and a Gate which act as a buffer.

5 METHODOLOGY AND DESIGN:

5.1 SYSTEM BLOCK DIAGRAM INCLUDING MPPT and DC-DC BOOST CONVERTER:

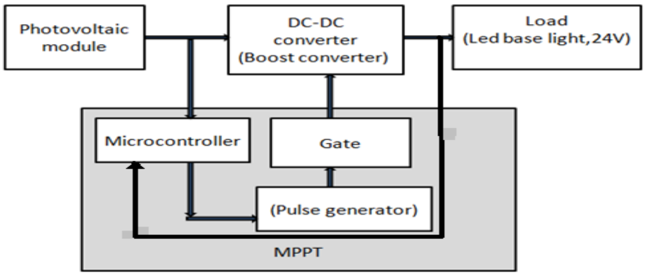

Figure 3 system block diagram

From the block diagram above, the DC-DC converter is used as a photovoltaic interface between the photovoltaic module and the load to power the load (Led base light, 24V). This is achieved by controlling the duty cycle of the DC-DC boost converter. From figure 3, the microcontroller tend to maximize the output power from the photovoltaic module by adjusting the duty cycle so that the photovoltaic module will always be at its maximum power at all times. This is done by continuously collecting samples of voltage and current from the output of the photovoltaic module including a reference voltage from the output of the converter as shown in figure 3 and employing the microcontroller to increase or decrease the voltage applied to the pulse generator (PWM) in order to change the duty cycle of the converter.

6 PHOTOVOLTAIC LABORATORY TEST RESULTS:

The design of the DC-DC converter requires input power which will be obtained from a photovoltaic module. The power will be define by the I-V and P-V characteristic curve as illustrated in figure 5.0 and 6.0. To determine these characteristic curves, the photovoltaic module with given specifications was tested in the lab. See specification in table 1.

The test was done in the laboratory using lab setup shown below in figure 4, to achieve the input voltage and current of the DC-DC converter. The test was done with radiation of 1000W/m² and with variation of load resistance using ohm's law (V=IR), to determine the input voltage and current. Also 660W/m², 370W/m² were also used to ascertain the variation of power when radiation is change.

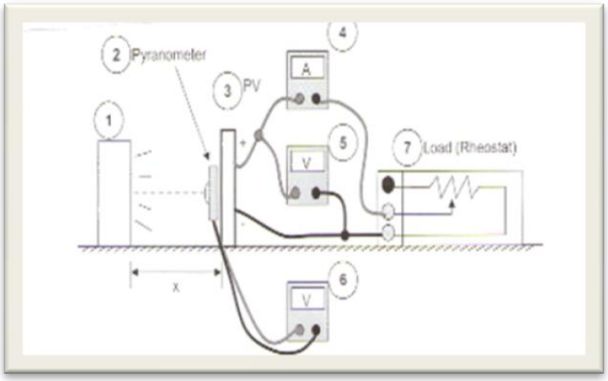

Figure 4, laboratory setup for photovoltaic module

From figure 5, each number represent different component in the setup and they are 1: halogen lamp, 2: Pyranometer, 3: Photovoltaic module, 4: Ammeter, 5,6 : Voltmeters and 7 : load (rheostat).

Table 2; represent the laboratory test results of the photovoltaic module at different irradiation. Also Figure 5 and 6 demonstrate the power, voltage and current at maximum power point which illustrate the changes in maximum output power of the module when radiation changes. In the laboratory test, a halogen lamp is use as sun ray and a pyranometer, to measure irradiation at different level. The pyranometer output is linear, 0.2mV per W/m². At standard test condition (STC), the photovoltaic module parameters are shown in the technical data sheet in table 1. The output power of the laboratory test result at 1000W/m² was quite different to that of the technical datasheet of the photovoltaic module due to the fact that the experiment was done indoor with a halogen lamp which affected the intensity of the radiation on the module.

Type	Cell	Size	Glass size	Weight	Max power	Max power voltage	Max power current	Open circuit voltage	Short circuit current
SR5-36	G-mono/poly	194*385*28	189*379	0.8	5	17	0.3	21.6	0.33

Table 1: Technical data sheet of photovoltaic module

Pyronometer reading = 200mV Irradiation = 1000W/m²				Pyronometer reading = 132mV Irradiation = 660W/m²				Pyronometer reading = 74mV Irradiation = 370W/m²				
Voltage	current	ohm	power	Voltage	current	ohm	power	Voltage	current	ohm	power	
0	0.2	0	0	0	0.139	0	0	0	0.109	0	0	Short cct. current
2.54	0.199	12.5	0.505	1.71	0.134	12.5	0.229	1.29	0.103	12.5	0.133	
3.36	0.199	16.7	0.668	2.25	0.133	16.7	0.299	1.71	0.103	16.7	0.176	
4.97	0.198	25	0.984	3.35	0.133	25	0.445	2.55	0.103	25	0.263	
6.58	0.196	33.4	1.289	4.42	0.131	33.4	0.579	3.38	0.102	33.4	0.345	
9.76	0.195	50	1.903	6.54	0.13	50	0.850	5	0.102	50	0.51	
12.01	0.192	62.5	2.306	8.09	0.129	62.5	1.044	6.24	0.102	62.5	0.636	
12.58	0.188	67.5	2.365	8.62	0.129	67.5	1.112	6.64	0.099	67.5	0.657	
13.37	0.180	75	2.407	9.58	0.127	75	1.217	7.45	0.099	75	0.737	
15.69	0.154	100	2.416	12.36	0.124	100	1.533	9.75	0.098	100	0.955	
15.94	0.142	112.5	2.263	13.39	0.119	112.5	1.593	10.83	0.096	112.5	1.039	
16.13	0.138	116.7	2.226	13.74	0.117	116.7	1.607	11.22	0.096	116.7	1.077	
16.34	0.131	125	2.141	14.27	0.114	125	1.627	11.99	0.095	125	1.139	
16.88	0.112	150	1.891	15.46	0.103	150	1.592	13.61	0.091	150	1.238	
17.05	0.098	183.4	1.587	16.55	0.09	183.4	1.489	15.18	0.081	183.4	1.229	
17.24	0.085	200	1.465	17.16	0.05	200	0.858	15.67	0.077	200	1.206	
18.44	0		0	18.14	0		0	17.48	0		0	Open cct. Voltage

Table 2: photovoltaic module test result at different radiation.

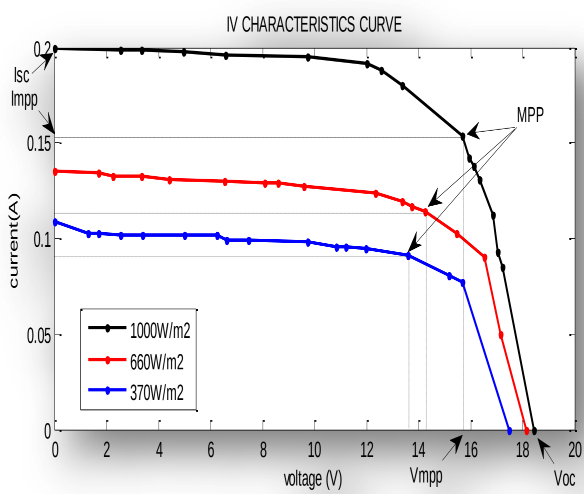

Figure 5, I-V characteristic curve at different irradiation level

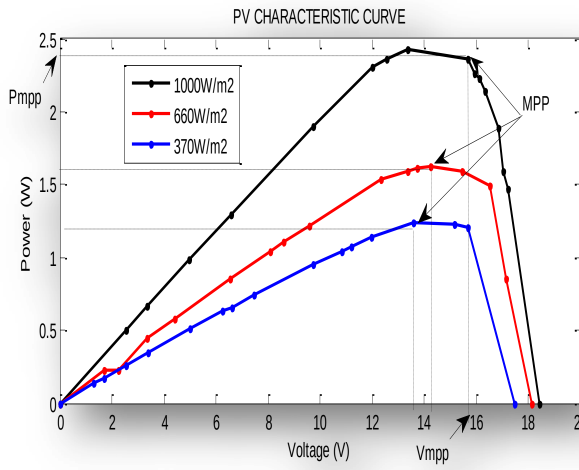

Figure 6, P-V Curve at different irradiation level.

7 DC- DC BOOST CONVERTER DESIGN AND RESULT ANALYSIS:

As stated above that DC-DC boost converter is used as photovoltaic interface and is design to boost the output voltage to 24V to meet the requirement of the load (led base light). Based on this fact some specification of the boost converter was assumed to meet the load demand, see table 3 and boost converter design equations as listed in equation (5), (6) (7) and (8). Equation (1) represent the boost converter transfer function where V_o= output voltage, V_i = input voltage and D represent duty cycle. Also F_s= switching frequency, L_o =boost inductance and C_o represent output capacitance.

$$\frac{Vo}{Vi} = \frac{1}{1-D} \qquad (5)$$

$$\Delta I= \frac{Vi*D}{Fs*L} \qquad (6)$$

$$\Delta V=\frac{Io*D}{Fs*C} \qquad (7)$$

Pi = Po =Vi*Ii = Vo*Io (Assume 100% efficiency of converter) (8)

SPECIFICATIONS	VALUE	UNIT
Input voltage (output voltage of photovoltaic module at 1000W/m²)	15.9	Volts
Input current (output	0.1598	Amps

current of photovoltaic module at 1000W/m^2)		
Out put voltage	24	Volts
Voltage ripples (5%)	1.2	Volts
Current ripples (10%)	0.0159	Amps
Input power (output power of photovoltaic module at 1000W/m^2)	2.55	Watts
Switching frequency	20000	Hertz

Table 3: design specifications.

With these equations above, Io, L, C and D were calculated and listed in Table 4 using resistive load (225.6Ω). See application of calculated values in figure 8 with simulation results in fig 9 –fig 14 using Pspice. It is also useful to adjust the values of each component including the duty cycle to achieve the required result.

CALCULATED	VALUE	UNIT
Duty cycle, D	33	Percent
Load resistance, R_o	225	Ohms
Output current, I_o	0.1064	Amps
Inductance, L	16.5	Henry
Capacitor, C	1.463µ	Farad

Table 4: design calculation

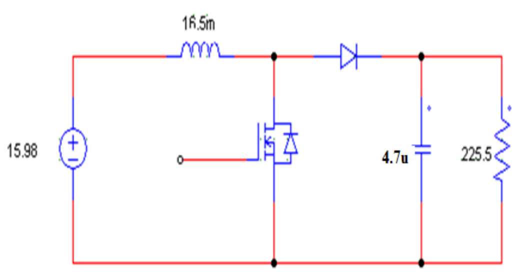

Figure 7 DC-DC boost converter simulations Circuit.

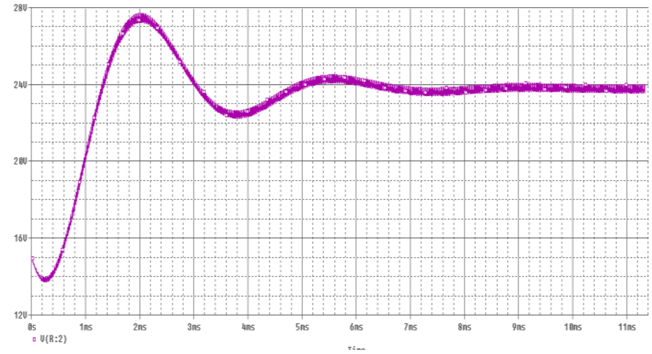

Figure 8 Output voltage of boost converter.

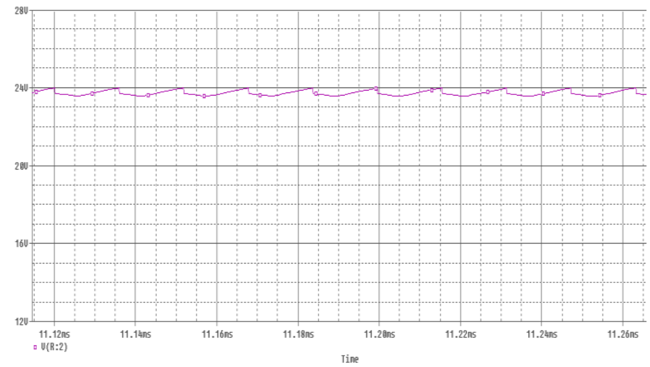

Figure 9: output voltage ripple, ΔV

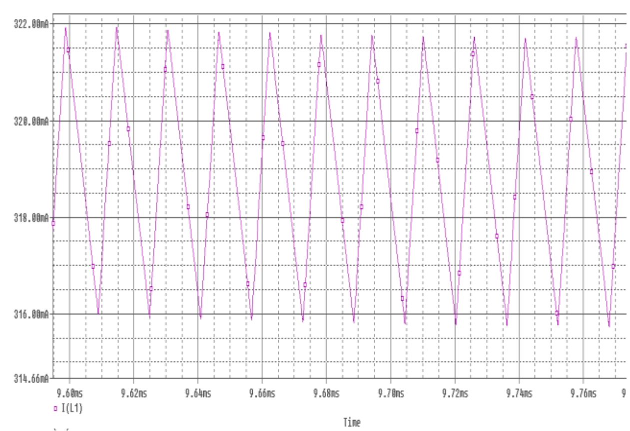

Figure 10: inductance current ripple

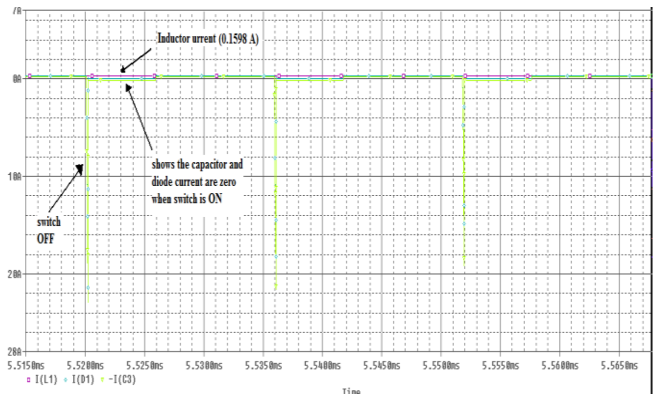

Figure 11: inductance current (L1), capacitance current (C3) and diode current (D1)

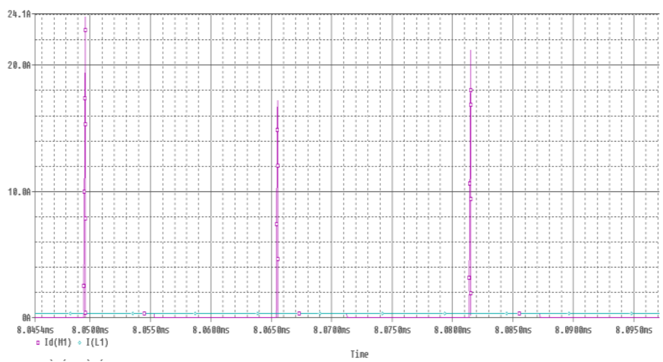

Figure 13: MOSFET ON and OFF time, (switching current)

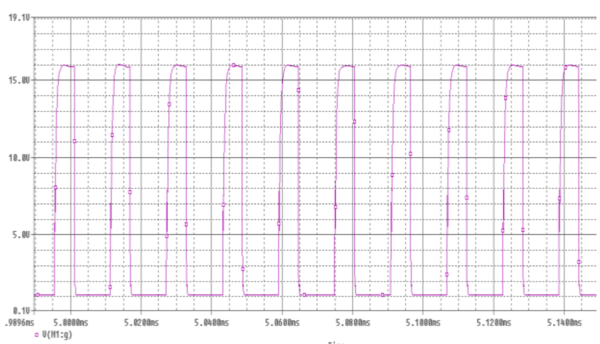

Figure 13 converter simulation duty cycle at 33% (PWM)

To enable total control of the maximum power point of the photovoltaic module, the power MOSFET (switch) of the boost converter must be switching ON and OFF as fast as possible to avoid saturation of the inductor. The verification of the response of the design DC-DC converter has been done from the above simulation results and in overall it proves that the converter works well and can be used as photovoltaic interface.

8. PULSE GENERATOR CIRCUIT:

Pulse generator circuit (PWM) is one of the major component in the propose MPPT design in the project because continuous changing of the duty cycle determines the steady state output voltage of the boost converter with regards to the input voltage. In this paper, an astable multivibrator (555 timer circuit), a current source and the output voltage of the microcontroller are used to produce the pulse wave modulation (PWM)/duty cycle.

9. MICROCONTROLLER:

The microcontroller plays an important role in changing the duty cycle of the boost converter by sending DC voltage to the pulse generating circuit after calculating and comparing the maximum powers of the photovoltaic module and reference output voltage of the converter at different intervals. The microcontroller operation will be based on the flow chart. The microcontroller was not applied but when testing the design system a voltage source was used in place of the controller to change the duty cycle when the output of the photovoltaic module (voltage source) was altered to achieve our desired output.

10. IMPLEMENTATION:

11. FULL SCHEMATIC OF PROPOSE DESIGN:

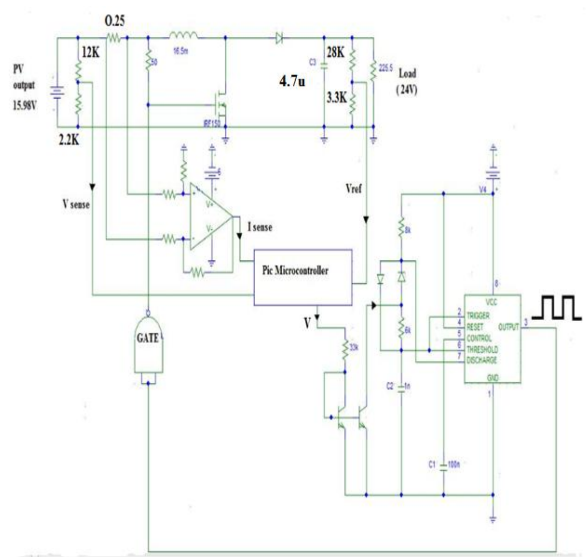

Figure 14 schematic of propose system diagram

12. IMPLEMENTATION RESULTS AND DISCUSION:

The design was implemented with the selected parts and using a voltage source to represent the Pic microcontroller as shown in figure 15. As the input voltage representing the photovoltaic module changes there is a corresponding change in output voltage then the voltage source representing the Pic microcontroller is altered to change the duty cycle so as to increase the output voltage to the desired value. See results for photovoltaic output of 15.9V, 14.2 V and 13.6V with duty cycle of 31%, 39% and 43% respectively.

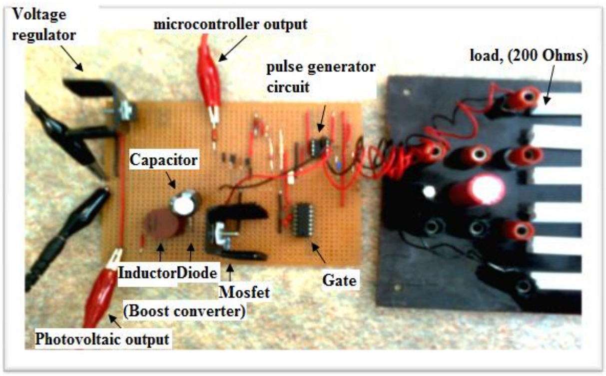

Figure 15 Implemented system diagram with selected parts.

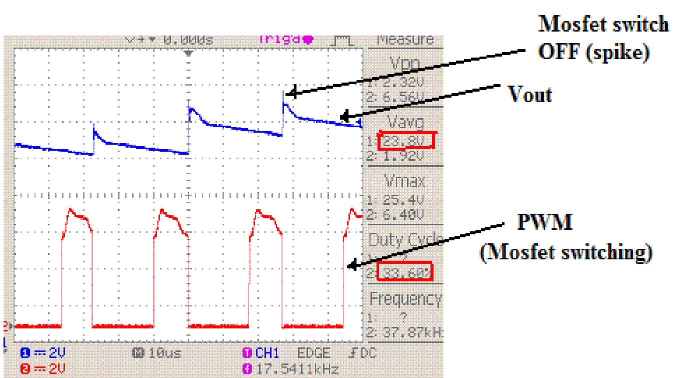

Figure 16 Output voltage of boost converter (23.8V) and duty cycle (33.6%) at MOSFET gate.

The simulation results of figure (8) and (13) of the theoretical design converter matches with the result of the practical application of the boost converter that is, 33% duty cycle and output voltage of 24 V with an input voltage of 15.9 V representing the output of photovoltaic module. A different was observe in peak to peak voltage of PWM signal with the simulation having a voltage of 16V peak to peak while the practical application has 6.56 V which is as a result of the value of resistance connected to the input of the MOSFET to increase the MOSFET gate current (I_D) which is different for both cases. The output voltage and duty cycle when a 15.9 V is applied from the photovoltaic module was achieved with a voltage of 3.4V (voltage source) assume to be generated by the microcontroller. The practical implementation also confirms the transfer function equation of boost converter ($\frac{Vo}{Vi} = \frac{1}{1-D}$).

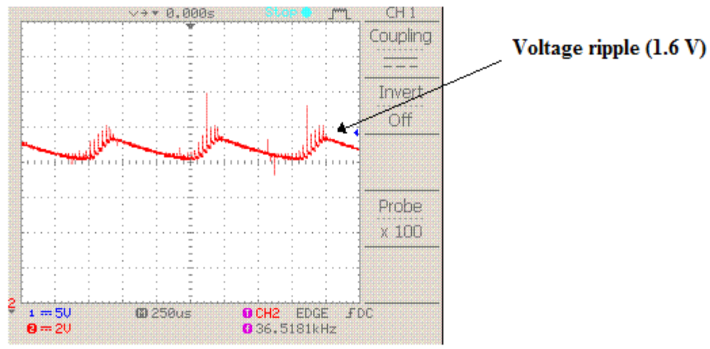

Figure 17 output voltage ripple

The capacitor of the boost converter determines the voltage ripple of the output voltage but does not have any significant impact on the magnitude of the output voltage. In the theoretical calculation a voltage ripple of 1.2V was estimated using a smaller capacitor as illustrated in figure 9, but during the practical implementation a bigger capacitance (4.7u) was use which affected the voltage ripple to 1.6V as shown above in figure 17 but it does not change the output voltage of 24 V. it was accepted because it suitable with our present load voltage (Led base light, nominal voltage of 24 V). The result shows that when the output of the photovoltaic module changes the design boost converter is capable of boosting the power to maximum power with a change on the duty cycle.

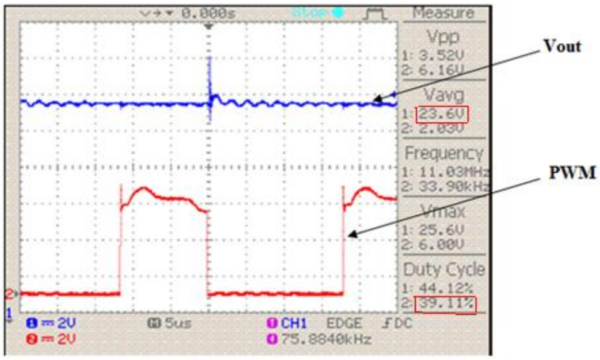

Figure 18 output voltage of boost when input voltage is 14.2V and duty cycle is 39% and input current 0.28 A with output voltage of microcontroller as 3.2V.

Figure 18 represent the output voltage and duty cycle (PWM) when a 14.2 V is applied at the input of the boost converter. The output voltage tends to meet average voltage of 23.6 V when the microcontroller (assume voltage source) was altered to 3.2 V , this action changes the duty cycle to 39% which is almost equal with the calculated value of 40% using the boost transfer function equation ($\frac{Vo}{Vi} = \frac{1}{1-D}$).

Figure 19 output of boost converter when input voltage is 13.6V and duty cycle is 43% and input current 0.3 A with output voltage of microcontroller as 3.0V.

Figure 19 represent the output voltage of the boost converter and duty cycle when 13.6 V was applied as the input voltage (output of photovoltaic module) of the converter. The output voltage was 23.9 V due to the change of output voltage of microcontroller (voltage source) to about 3.0 V. this action tend to adjust the duty cycle to 43.8% which agree with boost converter transfer function equation ($\frac{Vo}{Vi} = \frac{1}{1-D}$).

CONCLUSION AND FURTHER WORKS:

The aim of the paper is to design a DC boost converter and a Maximum power point tracker to optimize efficiency at all times. This was done through careful examination of the photovoltaic module data sheet to achieve a most desirable outcome, particularly with maximum power. The design was first carried out through a carefully design schematics of the system. The design of the DC-DC boost converter, pulse generator (PWM) for the project was successfully completed but an automated maximum power point tracker was not successfully achieved and will be look at separately. The practical implementation testing explains the behavior of the module during different irradiation and also to observe practical control of the MPPT. The DC boost converters operating in continuous conduction modes with maximum power point trackers have been studied and proposed.

Next steps will be:

- Assign a microcontroller
- Develop MPPT Algorithm/Flow chart and operation.
- Implementation on the proposed design.

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