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Buck Converter Output Voltage Control System Using Proportional Integral Differential Method on Solar Cell Battery Charging

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Abstract

Although fossil fuels are still readily available, their use is becoming less and less common. Solar energy produced by panels on the roof can be used as a source of power. Semiconductor-based solar panel technology can absorb photons from sunshine and transform them into ecologically beneficial electrical energy. Of course, a control device that regulates the electrical energy charging system is required when using solar cells as a power source to charge a battery. This device is typically referred to as a charge controller. The DC-DC converter of the buck type with a Ziegler Nichols-based Proportional Integral Differential (PID) control approach utilizing Arduino Uno is the control system utilized in this solar cell battery charging. The buck converter reduces and stabilizes the solar panel's output voltage following the requirements for charging the accumulator. For charging batteries, a set point voltage of 13.8 V is employed. By testing the converter with both static and dynamic loads, the research that has been done can produce results. The 35 Watt lamp static load test results with a fixed voltage source show that the set point voltage is 13 V and that it takes 28 s to attain a steady condition. When applied to dynamic loading using a battery charge of 12 V/7.5 Ah with a 20 WP solar panel source during hot, partly cloudy weather, the charging efficiency is 68 percent. A steady state of about 28 s may be claimed to be a satisfactory control system response.

Keywords

Battery Charging, Buck Converter, Control System, Solar Cell

INTRODUCTION

Electronic devices employ electrical energy sources more frequently than ever in the modern era of technological advancement. Because of this, the electricity consumption is so high, which can be problematic if the supply does not match the demand. In general, fossil fuels, whose supply is diminishing, continue to provide the majority of the world's electricity [1]–[3]. To find more effective energy sources, such as renewable alternative energy, one must solve problems. The semiconductor material used in solar cells allows photons from sunshine to be absorbed and transformed into electrical energy. Solar cells are also widely used and have comparatively minimal maintenance costs because they are believed to be ecologically benign [4]–[6]. Because not all of the energy from sunlight can be captured by the p-n junction, which functions by forcing electrons to travel from the semiconductor to negative contact, some of the sun's energy is lost as heat and the solar panel itself has a relatively low efficiency of less than 40%. The battery will suffer harm if the solar panel's output voltage, which is used by the charger, is not constant.

Because solar energy can change its radiation value at any time, a control is required to regulate its output during the solar-powered battery charging process. A buck-type DC-DC converter circuit is employed as the control. When the amount of solar radiation varies, buck converters are used to stabilize solar panel output so that the proper voltage level can be attained to charge the accumulator [7], [8]. It requires a tool to improve solar cell efficiency as a result of these issues. Numerous studies have covered various battery charging control system techniques. In earlier investigations, the Proportional Integral Differential (PID) management of the battery charging system was based on the Trial and Error technique [9]–[11]. The Cohen Coon method-based PID control has also been applied to battery charging. The control response seems to be relatively stable based on the two approaches results. The Ziegler Nichols method, which was used to control the temperature during the drying process of water hyacinth, was utilized as the basis for the research as well, and it produced a superior control response. Therefore, using the Ziegler Nichols-based PID control method, research was conducted that was a development of earlier study for this theme. With this study, a better control response for the solar cell battery charging process should be targeted possible.

BUCK CONVERTER

The DC-DC converter in use is a buck converter, which often has a lower output voltage than the input voltage. Figure 1 shows the schematic for a buck converter [12], [13]. The buck converter's construction, the buck

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converter's average output voltage for this tool, which employs a general design and is affected by the solar panel's fluctuating voltage, is 13 V. Therefore, it is still safe to use for the maximum charging voltage even with a design output voltage of 13 V. The battery is 13.8 V, and since there isn't much of a difference between that and the computation results, the system responsiveness is unaffected. In detail, the parameters are listed in Table I.

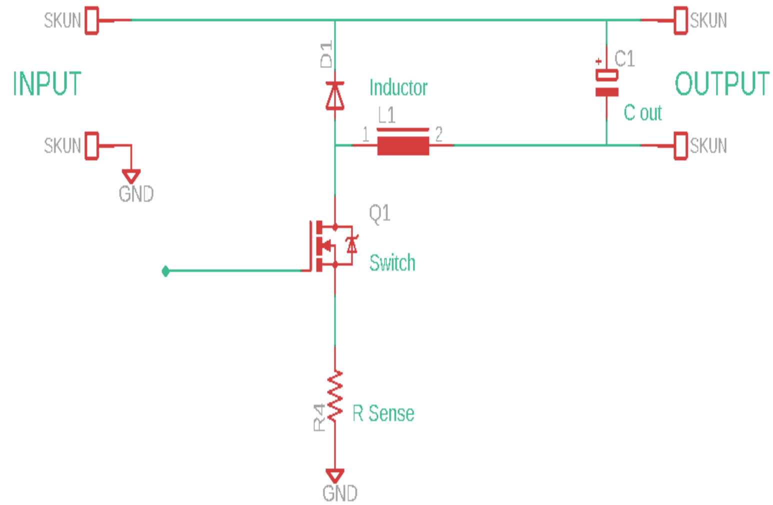

Figure 1. DC-DC Buck Converter Design

TABLE I
BUCK CONVERTER SPECIFICATION

No	Parameter	Symbol	Value
1.	Minimum voltage input	$V_{in\ (min)}$	5 V
2.	Maximal voltage input	$V_{in\ (max)}$	19 V
3.	Output voltage	V_{out}	13 V
4.	Maximum current output	$I_{out\ (max)}$	3 A
5.	Ripple voltage	ΔV_{out}	0.1 V
6.	Switching frequency	F_s	31 kHz
7.	Average voltage solar cell	V_{in}	14 V

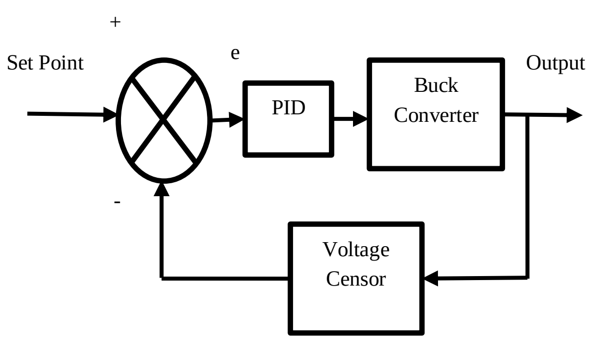

Figure 2. PID Control model

A control block diagram for the voltage on the buck converter is shown in Figure 2. The voltage reading obtained from the voltage sensor reading on the buck converter is required for the design of the PID control, which will be processed using a formula [9], [13]. These readings' outcomes will later be used to calculate the algorithm to

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determine the PID parameter value. Based on the graph, the response performance of the PID system is not good, so it requires the provision of parameter tuning with a good data retrieval method so that it can control the results of the oscillating and unstable curve [10], [14], [15]. Therefore, in this study, a study was conducted using the Ziegler-Nichols type 2 close loop method. In Table II, it can be seen the tuning value of the PID parameter is based on the method of the Oscillation curve.

TABLE II
TUNING PARAMETER OF PID CONTROL

Controller	Kp	Ti	Td
PI	0.45 K_{cr}	0.5 P_{cr}	0
PID	0.60 K_{cr}	0.5 P_{cr}	0.125 P_{cr}

PROCEDURE

This section provides a procedure for the whole working in this study based on the problem needs analyzing, defining parameter, system design, model presentation, partial simulation, producing, test, and improvement. Mechanical design is carried out to establish a protective function for electrical and electronic parts, as well as to increase product durability and provide a good appearance. A buck converter test circuit is shown in Figure 3. The Pulse Wide Modulation (PWM) source is the first stage that needs to be tested. The PWM source produced by the Arduino Uno is under the planned design, which is 31 Khz and duty cycle and can be altered. An input voltage of 18 VDC, a fixed frequency of 31 Khz, and a variable duty cycle is used to conduct the test. The duty cycle can be changed by increasing or lowering it. The duty cycle will be computed and processed in the PID system before being applied to the buck converter.

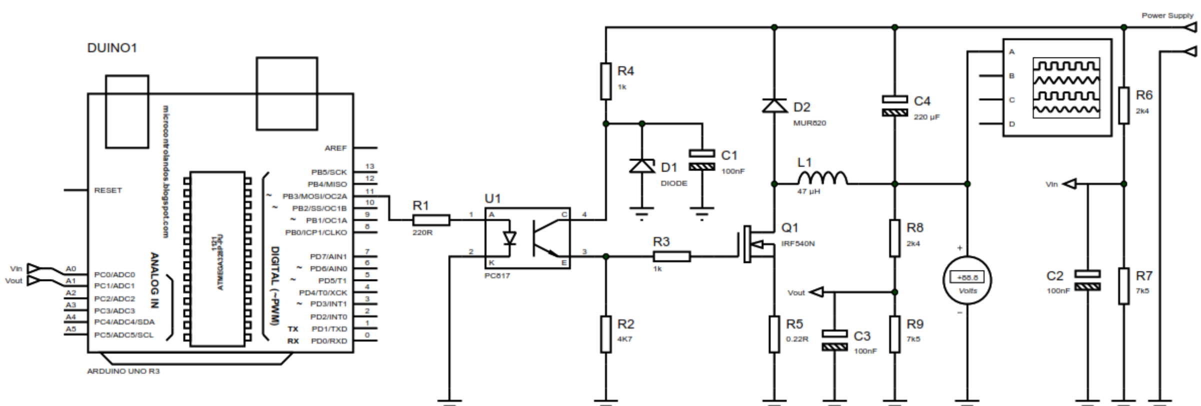

Figure 3. Testing system design

RESULT

The voltage response utilizing a PID controller was graphed considering Table III as a result of testing the system with a set point of 13 V without load. Analysis of the test's delay time, rising time, peak time, and settling time is possible from Figure 4. When the system is tested with a set point of 13 V and a 35 Watt lamp load, a graph showing the voltage response with a controller is produced. Table IV shows an analysis of the delay time, rise time, peak time, and settling time from Figure 5. When the charge controller with a set point of 13 V is connected without utilizing a load, the actual value obtained is practically the same as the supplied set point, where the output voltage produced ranges from 13-13.1 V, according to the findings of testing the system response from these two graphs. The charging and discharging of the capacitor can function at their best when a charge controller with a set point of 13 V is connected to the load. When there is a small variation between the actual result and the supplied set point, the voltage can function steadily.

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TABLE III
SYSTEM RESPONSE NO LOAD

No	Specification	Result
1	Rise time (Tr)	600 ms
2	Delay time (Td)	200 ms
3	Peak time (Tp)	800 ms
4	Settling time (Ts)	25.6 s

TABLE IV
SYSTEM RESPONSE WITH LOAD

No	Specification	Result
1	Rise time (Tr)	14 s
2	Delay time (Td)	2 s
3	Peak time (Tp)	24 s
4	Settling time (Ts)	28 s

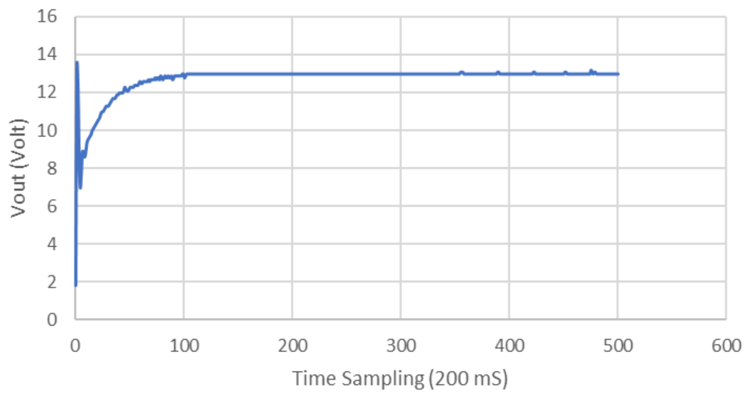

Figure 4. Testing result of PID system without load

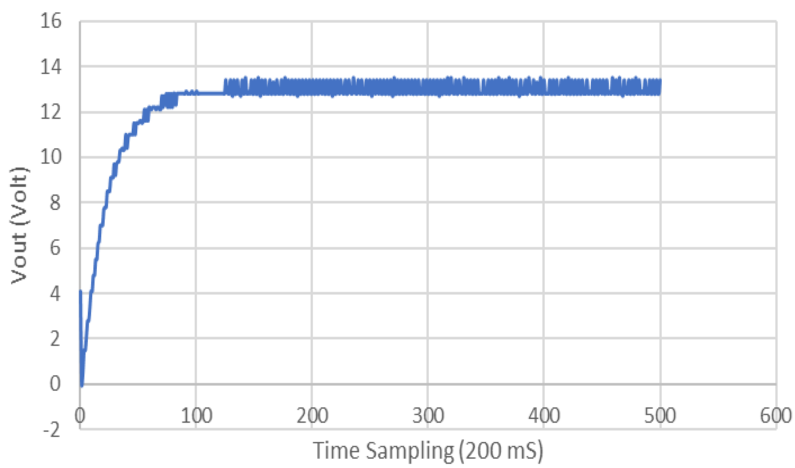

Figure 5. Testing result of PID system with load

The output voltage (Vout) was found to increase with a change in duty cycle in tests utilizing an input voltage of 18 VDC, a fixed frequency of 31 Khz, and a variable duty cycle. One can modify the output produced by adjusting

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the duty cycle. Before being used in the buck converter, the duty cycle will be estimated and processed in the PID system. In detail, the buck converter performances are provided in Table V, Figure 6, and Figure 7 with various duty cycles. The test results for the solar panel test circuit are shown in Table VI, where it is clear that the output voltage and current values provided by the solar panels are subject to change at any moment due to the influence of variations in the amount of sunlight they can catch.

TABLE V
BUCK CONVERTER TEST

No	Duty Cycle (%)	Vout (V)
1	5	0,48
2	10	2,24
3	15	4
4	20	5,92
5	25	7,56
6	30	10,004
7	35	11,204
8	40	11,88
9	45	13,56
10	50	15,16

TABLE VI
SOLAR CELL TEST RESULT

No	Time	Vout (V)	Iout (A)
1	09.30	19.8	0.89
2	09.45	21.0	0.91
3	10.00	21.1	0.92
4	10.15	19.9	0.93
5	10.30	18.7	0.21
6	10.45	21.1	0.92
7	11.00	18.9	0.71
8	11.15	21.0	0.15
9	11.30	20.3	0.62
10	11.45	20.4	0.23
11	12.00	20.3	0.62
12	12.15	20.2	0.28
13	12.30	20.3	0.35
14	12.45	20.2	0.38
15	13.00	18.7	0.09

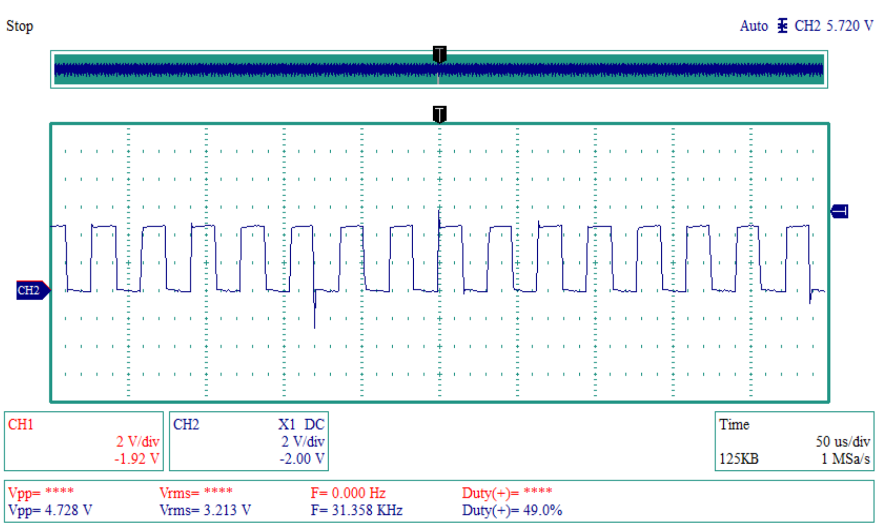

Figure 6. PWM test based on 31KHz and duty cycle 50 %

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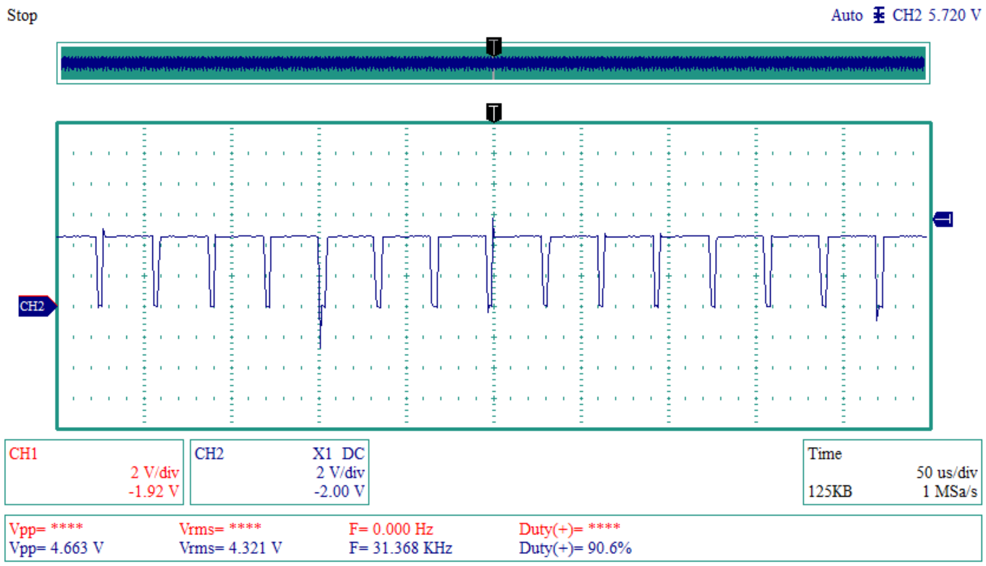

Figure 7. PWM test based on 31KHz and duty cycle 90 %

Additionally, testing of the entire contraption was done using a 20 WP solar panel to charge the accumulator from 09:00 to 12:15 on various days. Based on the test results, it can be seen that the input voltage value depends on the amount of sunlight and the condition of the accumulator; when the accumulator voltage is low, the input voltage is also low. In this test, there is a change in the large increase in the value of the accumulator voltage; specifically, in the first test data, the voltage of 12.2 V becomes 12.9 V and the second test data is 13 V to 13.8 V. This proves that the accumulator is charged. In the meantime, the output current's value is also influenced by the solar panel's current level. As can be observed, when the output voltage is low by 13.2 V and the current value is low at 0.03 A owing to variations in sunshine intensity, the accumulator is still charging. This device's battery is charged at a set point voltage of 13.8 V. Therefore, the charging current is low (0.52 A) and the input voltage is high (15.8 V) when the accumulator voltage is entirely identical at 13.8 V. When the accumulator voltage exceeds 9 V, the accumulator can be used and the relay load will turn on.

CONCLUSION

It is known that the buck converter output voltage control system on the solar cell battery charging has been successful with the PID method of Ziegler-Nichols oscillation curve and found the value of Kp based on the results of the tests that have been conducted and the analysis of the results of the design of the buck converter circuit with its constituent components, including inductor 49.92 H, capacitor 24.19 F, MUR460 series Schottky diode and IRF540N series MOSFET. When testing the PID response, it is observed that the steady state lasts approximately 28 seconds, indicating that the control system's response is good. As a result, when applied to dynamic loading carried out on a battery charging of 12 V/7.5 Ah with a solar panel source of 20 WP, the charging efficiency is 68 percent when the weather is hot and partly cloudy. It is possible to conduct additional research on buck converters using other dc-dc converter types.

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