Design of Adaptive DC Power Supply with Microcontroller Based Cuk Converter Circuit

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Abstract. Nowadays, the need for equipment sourced from DC power supplies is increasing. One of the DC –DC converter topology that can be DC source is Cuk Converter. Currently, we need an adaptive power supply that can generate current and voltage according to the power required by the load automatically. In this research, the Cuk-Converter circuit is driven through the Arduinonano as a pulse generator and circuit control system. The microcontroller has set a minimum current of 520mA to charge the battery. The test was carried out with a 12 Volt DC battery source, the output of the Cuk-Converter was a 3.7 Volt battery with a capacity of 50,000 mAh and 3Ah, and a 12 Volt 3 Ah accumulator. The output of the Cuk Converter is set in the range 2-19 Volt DC. The results show that the Cuk-Converter can charge the test battery with a minimum current of 520 mA and a duty cycle in the range of 27-50%. This result performed the average error of the circuit and calculation was 13.9%.

I. Introduction
In modern times, much electronic equipment uses DC voltage as its source, but the electricity provided by the electricity company is in the form of AC voltage. The development of PV off-grid application requires conversion to AC system. The conversion from DC to AC power has extra power losses during the process [1].

There are several ways to minimize power losses, one of which is the use of a DC to DC conversion system by providing DC output from DC source. The DC power supply is an electronic circuit that can produce direct current. The power supply can also be used as a device that supplies electrical energy for one or more electrical loads [2]. DC power supplies have many types, one of which is an adjustable power supply, which not only has one voltage variation but several voltage variations depending on the potential setting and capacity.

Cuk is a working DC Converter as an increase or decrease the voltage that can adjust the output voltage and can function to improve power quality and efficiency [3]. CUK Converter also provide capacitive isolation which protects against switch failure [4] and can be used to improved power factor [5].

Based on this background, this research aims to design a power supply that can output current and voltage according to the nominal power required by the load automatically. The proposed system for adjustable power supply consist of DC source, CUK converter, voltage and current Sensor, and microcontroller as switching control (Figure 1). CUK converter topology is used to produce variable
output from a fixed DC source. Cuk converter is suitable for this research because Cuk design is having better characteristics on ripple content of currents compared to all basic DC-DC converters[6].

![CUK Converter System for Variable Load](image)

**Fig. 1. CUK Converter System for Variable Load**

### 2. Battery Charging Characteristics

Data collection about battery charging is used as a reference for the logic of the system to be made. By comparing the battery charge in empty and full condition, it can be determined battery charging characteristics. The test is done by reading current and voltage sensors installed on the load. Every increase in voltage from the power supply will be read by the current and voltage sensors. When the condition is full, the minimum voltage required by the battery for a charging current of 0.17 A is 13 Volts. This voltage will continue to rise until the level of 14.2 Volts with a maximum charging current of 0.9 A. When the battery is empty, the minimum voltage required for a charging current of 0.04 A is at the 9.5 Volt level. The voltage and charging current will continue to increase gradually to the level of 14.5 Volts with a charging current of 0.528 A. From the data above, it can be concluded that charging an empty battery requires a lower voltage than charging a battery in full condition.

![Battery Full Condition](image)

**Fig. 2. Battery charging characteristics on full condition**

### 3. CUK Converter Design

#### 3.1. Cuk Converter

The Cuk converter circuit is a DC-DC converter that has an output voltage greater or less than the input voltage, where the output voltage becomes negative. This circuit is the main circuit consisting of inductors, switches, diodes, and capacitors. The construction of CUK Converter includes two inductors and two capacitors for storing the energy therefore it is a converter circuit with order 4[6]. Unlike any other converter using an inductor as an intermediary, CUK converter relies on the capacitor to transfer energy from the input to the output. The advantage of this converter is a
continuous current which is on the input and output side, while the weakness is the reactive value of the component and its magnitude of currents in switches, diodes, and capacitors C1[7]. The thing that must be known is the amount of output that will be issued so that the amount of Duty Cycle can be determined.

![Battery Empty Condition](image1)

**Fig. 3.** Battery charging characteristics on empty condition

![CUK Converter Topology](image2)

**Fig. 4.** CUK Converter Topology

The output equation of CUK Converter is[8]:

\[ V_o = -V_s \left( \frac{D}{1 - D} \right) \quad (1) \]

The equation for sizing current in Inductor at input side (L1) is:

\[ IL_1 = \frac{P_s}{V_s} \quad (2) \]
The equation for sizing current in Inductor at output side (L2) is:

\[ I_{L2} = \frac{P_s}{-V_o} \]  

(3)

The equation for sizing L1 minimum for continuous current is:

\[ L_{1_{\text{min}}} = \frac{V_oD}{f \Delta I_{L1}} \]  

(4)

The equation for sizing L1 minimum for continuous current is:

\[ L_{2_{\text{min}}} = \frac{V_oD}{f \Delta I_{L2}} \]  

(5)

The equation for sizing C1 is:

\[ C_{1_{\text{min}}} = \frac{V_oD}{R \Delta V_{C1}} \]  

(6)

The equation for sizing C2 is:

\[ C_{2_{\text{min}}} = \frac{(1-D)}{8 I_{o} f^{2} (\Delta V_{o}/V_{o})} \]  

(7)

The proper design of CUK Converter specification for adjustable Power Supply as follows in table 1.

| Parameter                        | Rating                  |
|----------------------------------|-------------------------|
| DC Source Voltage (Vin)          | 12 V                    |
| Output Voltage (Vout)            | 2-19 V                  |
| Inductor Current Ripple (\Delta iL) | 40% of Io               |
| Voltage Output Ripple/C2(\Delta V) | 1%                     |
| Voltage Ripple of C1             | 5%                      |
| Frequency Switching(F)           | 25kHz                   |

From Figure 5 it can be seen that the CUK converter circuit requires switching of gates, diodes, inductors, and capacitors. Then the design is carried out with the following parameter data:

| Parameter                        | Specification |
|----------------------------------|---------------|
| DC Source Voltage (Vin)          | 12 V          |
| Output Voltage (Vout)            | 2-19 V        |
Switching Frequency (f)  25kHz
Inductor 1(L1)       14mH
Capacitor 1(C1) 10μF
Inductor 2 (L2) 16mH
Capacitor 2(C2) 3.3μF

3.2. Design the Inductor
The picture below is an inductor that has been wrapped and measured with an LCR meter. The inductors use ferrite cores (generally used for flyback transformers). The advantages of inductors with ferrite cores are:

a. Produces a larger inductor value because it has a magnetic core.
b. It is easier to wrap copper on the inductor core.
c. The physical form is very minimalist and can be neatly installed on the PCB.

![Fig. 7. Making inductor with LCR meter](image)

The Inductor design used:

a. The maximum current for L1 is 1.6 A and the maximum current for L2 is 2 A, so use an enamel wire with a diameter of 0.8 millimeters.
b. The minimum inductor value is multiplied by 10 so that the output voltage can be continuous while being loaded. Based on the calculation, L1 is 14mH, and L2 is 16mH.

3.3. MOSFET Switching
Mosfet design used:

a. Using a frequency of 25,000 Hz, the MOSFET is capable of switching at a frequency of 1 Mhz.
b. The working voltage is 12V, the MOSFET is capable of working at a 55V Drain-Source voltage and a Gate-Source voltage of 20V.
c. Working current of 2 amperes, the MOSFET can work at a current of 49 Ampere on Drain.

This circuit is a control circuit on the MOSFET which consists of an optocoupler, power supply, resistor, and PWM generator. The MOSFET driver functions as a PWM signal amplifier. The following is the MOSFET Driver circuit scheme used:
4. Schematic and Flowchart

4.1. Schematic Diagram

![MOSFET Driver Circuit](image1)

**Fig. 8. MOSFET Driver Circuit**

![Block diagram circuit](image2)

**Fig. 9. Block diagram circuit**

DC Source : 12 Volt 2 Ampere.
Cuk Converter : 12 Volt input and 2-19 Volt output
Sensor : INA219 (DC Current and Voltage Sensor)
Load : 3.7V 50Ah battery and 12 V 3Ah battery
Mikrocontroller : Arduino Nano.

4.2. Flowchart System
To understand the workflow of flowchart Figure 11 is described as follows:
a. The system starts from PWM initialization in the circuit.
b. The sensor reads current and voltage at the output.
c. When the current reading is less than 520mA, the duty cycle will be increased by 1% per 0.5 second so that the output voltage is greater.
d. The sensor reads the current and voltage at the output.
e. When the sensor reading is greater than 520mA, the duty cycle will stop being increased
5. Hardware and Result

5.1. LCD Display of System Configuration

In Figure 11, LCD displays voltage, current, pwm and standby conditions. Voltage and current is the reading from the sensor, pwm is the width of the pulse signal used in the circuit, standby is an ongoing process. In standby condition, it means that the appliance is in a state ready for use.

In Figure 12, the values of voltage, current, and PWM will change. The value of the voltage and current will increase according to the increase of the duty cycle. On the LCD, the circuit works in the initialization mode, which means the program increases PWM by 1% every 0.5 seconds to find a minimum current of 520mA, when the minimum current has not reached 520mA, the duty cycle will continue to be increased by 1% for 0.5 seconds.
Fig. 13. LCD display “Charging” condition

From the figure 13, 5.97 Volt is the output voltage, 563.10 mA is the current generated by the circuit, PWM 28% is the pulse width used as the duty cycle in the circuit, and "charging" is the work process of the circuit which means that the device is charging the battery.

Hardware Testing

At these stages, testing is carried out on each component of the circuit. The test results will be used as a comparison between the design and the hardware that has been made. Several parts will be tested or measured. Figure 14 is the whole circuit of converters that have been made. In this circuit, the source used is a power supply that has 12 voltage values and the output voltage is 2 V to 19 V.

Fig. 14. Cuk Converter Circuit

a) TroubleShooting Testing with 50% Duty Cycle

1. Arduino PWM Output

Fig. 15. Output of PWM Arduino for 50% duty cycle

2. Optocoupler PWM Output
3. MOSFET Output

4. CUK Converter Output

From Figure 15-18, it is found that all components starting from the Arduino PWM, the driver (optocoupler), and MOSFET can work properly. The microcontroller can produce a duty cycle as desired. The driver can increase the voltage from the Arduino and the MOSFET can work as a switch with the correct duty cycle value. The output of the CUK Converter is negative according to the theory.

b) Hardware Laboratory Testing with Load

| Load       | Duty Cycle | Vo Theory | Vo Hardware | Error (\%) |
|------------|------------|-----------|-------------|------------|
| 1kΩ, 0.25 watt | 25%        | -4 V      | -3.32 V     | 17         |
### Table 4. CUK Converter testing with battery load

| No | Load      | Duty Cycle | Vo Theory | Vo Hardware | Error (%) |
|----|-----------|------------|-----------|-------------|-----------|
| 1  | 3.7 V 50Ah battery | 27%        | 4.43 V    | 5.88 V     | 32.7      |
| 2  | 7.4 V 50Ah battery  | 38%        | 7.35 V    | 10.27 V    | 39.7      |
| 3  | 12 V 3Ah battery    | 50%        | 15 V      | 17.58 V    | 17.2      |

Average error (%) 29.8
From Figure 19-21, Cuk-Converter circuit produces a voltage of 5.88 Volt and a current of 526 mA with a duty cycle of 27%, which can be used to charge a 3.7 Volt 50Ah battery. In the process of charging a 7.4 V 50Ah battery with a 38% duty cycle, the CUK Converter can produce an output voltage of 10.27 V and a charging current of 569.5 mA. When charging a 12V 3Ah battery, the CUK converter produces a voltage of 17.58 V and a charging current of 545.3 mA at a duty cycle of 50%. Result from table 3 and table 4, CUK Converter has average error 13.9%. Error in battery test is greater because power that passes through the circuit is greater than resistor load.

6. Conclusion
The CUK Converter design for adaptive DC power supply can results different output for the 3 types of test batteries. The circuit can charge a minimum current of 520 mA and the Closed Loop system can works properly for charging the battery. The hardware can display specified voltage and current required by the load.

Acknowledgments
The Authors wish to thank technical staff from Industrial Power Electronic Laboratory, Electrical Engineering, State Polytechnic of Madiun for their help in support technical work and data retrieval.

References
[1] Taufik T and Taufik M 2012 The DC House Project: Promoting the use of renewable energy for rural electrification 2012 International Conference on Power Engineering and Renewable Energy, ICPERE 2012
[2] Cahyadi M, Nasrullah E and Trisanto A 2016 Rancang Bangun Catu Daya DC 1V–20V Menggunakan Kendali P-I Berbasis Mikrokontroler J. Rekayasa dan Teknol. Elektro
[3] Hakim M H, Handoko S and Karnoto 2017 Analisis Perbandingan BuckBoost Converter dan CUK Converter dengan Pemicuan Mikrokontroller Atmega 8535 untuk Aplikasi Peningkatan Kinerja Panel Surya Transmisi Transmisi 18 3
[4] Kim K A and Krein P T 2010 Photovoltaic converter module configurations for maximum power point operation Proceedings of the 2010 Power and Energy Conference at Illinois, PECI 2010
[5] RS.Chafle, Vaidya U B and Z.J.Khan 2013 Design of CUK Converter with MPPT Technique Int. J. Innov. Res. Electr. Electron. Instrum. Control Eng.1 161–7
[6] K.D J, Daniel A E and Unnikrishnan A 2017 Interleaved cuk converter with improved transient performance and reduced current ripple J. Eng.
[7] Putra H P, Suryoatmojo H and Anam S 2016 Perbaikan Faktor Daya Menggunakan Cuk Converter pada Pengaturan Kecepatan Motor Brushless DC J. Tek. ITS
[8] Hart D W 2011 Power Electronics (New York: McGraw-Hill)