The Design of a DC Power Supply Subsystem of an Office Environmental Control System

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Abstract

The purpose of this project is to design and simulate a DC Power Supply(DPS) in the circuit simulation software LTspice. The DPS supplies power to an office environmental control system. The design was produced iteratively by splitting the DPS into sections and designing each section one by one to ensure each component functioned as desired according to given specifications. Each section was simulated and tested against calculated results before designing the next section in the scope, in order to ensure the section of DPS functioned correctly. Transient Analysis and DC Analysis was performed when simulating the sections and complete circuit in LTspice. The final result was a DPS that provided 4 distinct outputs, each with 9V at 200mA and 5V at 150mA voltage output, that could support and power all subsystems of the office environment simultaneously.

Introduction

This report details the design, development, and testing of a DC power supply(DPS) for an office environmental control system. The office environmental control system is comprised of 4 subsystems, the Access Control, Lighting Control, Temperature Control, and DC Power Supply Subsystems. A Multi-Output transformer is provided, with a secondary current rating of 1A and secondary voltages of 3, 6, 9, 12, 15, 18V_{rms}. The DPS must also use a Bridge Full Wave Rectifier, which must be constructed from 4 discrete diodes. The DPS must power and sustain all the subsystems simultaneously. The DPS must be driven by the mains wall outlet of the office. The DPS must provide 4 distinct outputs, and each must provide output voltages of 9V at 200mA and 5V at 150mA. The DPS must be simulated and tested in LTspice.

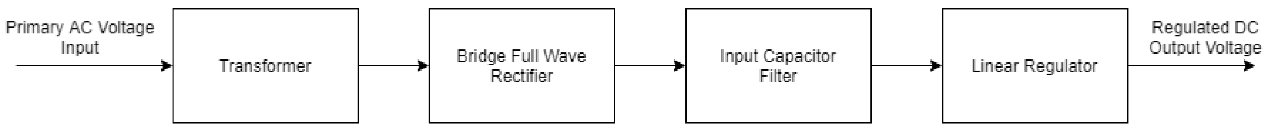
DPS Subsystem Design

DPS Block Diagram

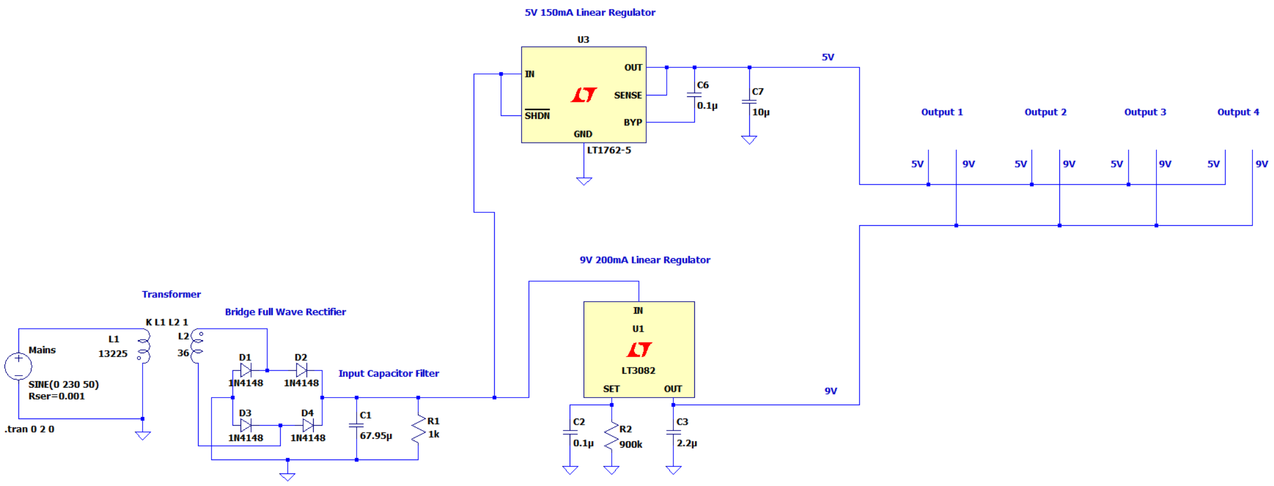
The DPS is comprised of 4 main sections:

- The Transformer
- The Bridge Full Wave Rectifier
- The Input Capacitor Filter
- The Linear Regulator

These sections are illustrated as Block Diagram:



DPS Circuit Schematic



Transformer Design

The required output of the circuit is 9V and 5V. The multi-output transformer has the following secondary voltages available: 3, 6, 9, 12, 15, 18 V_{rms}.

In order to achieve the required output voltages, the chosen secondary voltage should be as close to the desired output value as possible, but not equal to it, since through the process of rectification and regulation, the voltage will decrease before the final output is achieved. In this case it would be appropriate to use the $12V_{rms}$ secondary voltage from the transformer.

The transformer will be designed to give a secondary output voltage of $12V_{rms}$, using the mains outlet as the primary input voltage source.

V_p = mains = $230V_{rms}$ at 50Hz in South Africa

$V_s = 12V_{rms}$

$$\text{Turns Ratio} = V_p/V_s$$

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$= 230/12$

$= 115/6$

LTspice uses inductors to simulate transformers. In order to correctly simulate a transformer, 2 inductors will be coupled together and their inductance ratio will be used to step down the voltage instead of the turns ratio.

$$L_p/L_s = (V_p/V_s)^2$$

$L_p/L_s = (V_p/V_s)^2$

$= (115/6)^2$

$= 13225/36$

Setting the primary inductor to 13225 and the secondary to 36 will yield a step-down voltage of $12V_{rms}$.

Bridge Full Wave Rectifier Design

The $12V_{rms}$ secondary voltage is converted from an AC voltage to a pulsating DC voltage using a Bridge Full Wave Rectifier. The rectifier must be constructed using 4 diodes and uses a resistive load.

The 1N4148 Silicone Diode component in LTspice will be used to construct the Bridge Rectifier.

The expected output after the voltage has been rectified is:

$$V_O = V_{in} - 1.4V$$

$V_O = V_{in} - 1.4V$
$= 12 - 1.4$
$= 10.6V$

The expected diode current through the bridge loop is given by:

$$i_D = V_O/R_L$$

Where R_L is the resistive load and has a value of 1 kilo ohm.

$i_D = V_O/R_L$
$= 10.6/1k$
$= 10.6mA$

The expected voltage on the n-side of each diode is given by:

$$V_{D(nside)} = V_{in} - 0.7$$

$V_{D(nside)} = V_{in} - 0.7$
$= 12 - 0.7$
$= 11.3V$

Input Capacitor Filter Design

The input capacitor filter is driven by the bridge full wave rectifier, and produces a DC output voltage with a ripple voltage. This is required in order for the voltage to be regulated correctly into a constant DC output voltage during the regulation process.

The amount of ripple in the circuit, as a percentage of the ripple factor, must be chosen in order to determine the capacitance value. For this circuit a ripple factor of 5% will be chosen.

$$\%r = (V_{r(rms)}/V_{O(DC)}) \times 100$$

Where $V_{r(rms)}$ is the Ripple Voltage and $V_{O(DC)}$ is the desired DC output voltage. $V_{O(DC)}$ will be taken as 9V, since the capacitor needs to be able to filter for the greatest desired output, which will also in turn filter for the smallest desired output.

$\%r = (V_{r(rms)}/V_{O(DC)}) \times 100$
$5 = (V_{r(rms)}/9) \times 100$
$0.05 = (V_{r(rms)}/9)$
$V_{r(rms)} = 0.45$

The Peak-to-Peak Ripple Voltage must be determined in order to calculate the capacitance, and is given by:

$$V_{r(p-p)} = 2\sqrt{3}\,(V_{r(rms)})$$

$V_{r(p-p)} = 2\sqrt{3}\ (V_{r(rms)})$
$= 2\sqrt{3}(0.45)$
$= 1.56V$

The capacitance is given by:

$$C = (V_{O(p)}/2fR_LV_{r(p-p)})$$

Where f = 50Hz, R_L is the load resistor, and $V_{O(p)}$ is the output voltage at that point.

$C = (V_{O(p)}/2fR_LV_{r(p-p)})$
$= (10.6/2(50)(1000)(1.56))$
$= 67.95\mu F$

Linear Regulator Designs

The filtered voltage is inputted to the regulator and a constant regulated DC voltage is outputted.

A 9V at 200mA and a 5V at 150mA DC voltage are required at the output, therefore 2 linear regulators are required in order to achieve the desired output.

For the 9V output:

The LT3082 200mA regulator will be used to regulate the voltage.

The datasheet for the LT3082 details that:

- There is a maximum output current of 200mA
- It has an input voltage range of 1.2V to 40V
- The inclusion of 2.2uF capacitors keeps it stable
- It has an adjustable output voltage
- It has a small load regulation

These specifications make this regulator suitable for producing a 9V output at 200mA by using the 10.6V filtered voltage as an input.

In order to get an output voltage of 9V, the R_{set} component is set to 900k. There is current source of 10μA in the regulator and the regulated output voltage is determined by:

$$V_O = 10\mu A(900k)$$

$V_O = 10\mu A(900k)$
$= 9V$

Therefore the expected output of the regulator is 9V at 200mA.

For the 5V output:

The LT1762-5 150mA regulator will be used to regulate the voltage.

The datasheet for the LT1762-5 details that:

- There is an output current of 150mA
- It has an input voltage range of 1.8V to 20V
- It has a fixed output voltage of 5V
- The inclusion of a 2.2uF capacitor keeps it stable
- It has a small load regulation

These specifications make this regulator suitable for producing a 5V output at 150mA by using the 10.6V filtered voltage as an input.

Simulated Results

DC Analysis

```
       --- Operating Point ---

V(n005):        0               voltage
V(n008):        5.30114e-019    voltage
V(n006):        5.30114e-019    voltage
V(n002):        -4.1628e-022    voltage
V(n007):        -3.75026e-028   voltage
V(n004):        9.16983e-019    voltage
V(n003):        4.00988e-024    voltage
V(n001):        -1.44368e-025   voltage
I(C7):          -1.44334e-042   device_current
I(C6):          -4.14784e-043   device_current
I(C3):          2.01736e-036    device_current
I(C2):          -0              device_current
I(C1):          -2.82862e-038   device_current
I(D4):          -1.78614e-025   device_current
I(D3):          -1.78614e-025   device_current
I(D2):          -1.78614e-025   device_current
I(D1):          -1.78614e-025   device_current
I(L2):          0               device_current
I(L1):          0               device_current
I(R2):          -4.16696e-034   device_current
I(R1):          -4.1628e-025    device_current
I(Mains):       0               device_current
Ix(u1:2):       4.16696e-034    subckt_current
Ix(u1:3):       -2.00304e-036   subckt_current
Ix(u1:5):       -3.41664e-018   subckt_current
Ix(u3:1):       1.37481e-031    subckt_current
Ix(u3:2):       -1.45777e-031   subckt_current
Ix(u3:3):       -3.14616e-029   subckt_current
Ix(u3:4):       -5.90513e-026   subckt_current
Ix(u3:5):       -1.68593e-027   subckt_current
Ix(u3:8):       6.07372e-026    subckt current
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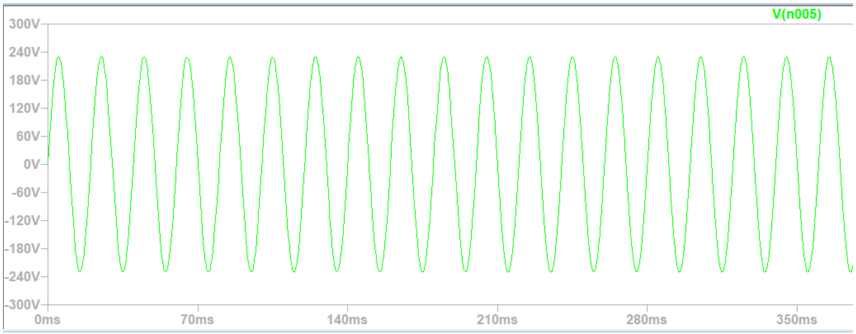
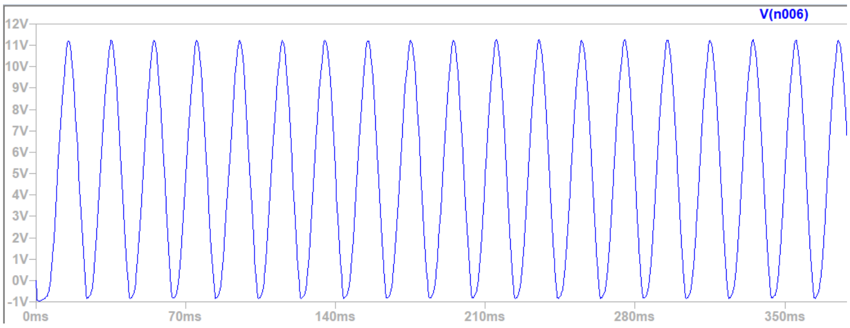
Transient Analysis

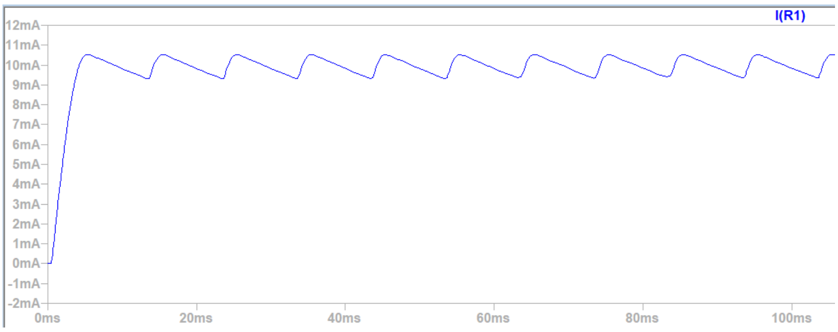
Mains Input Voltage:



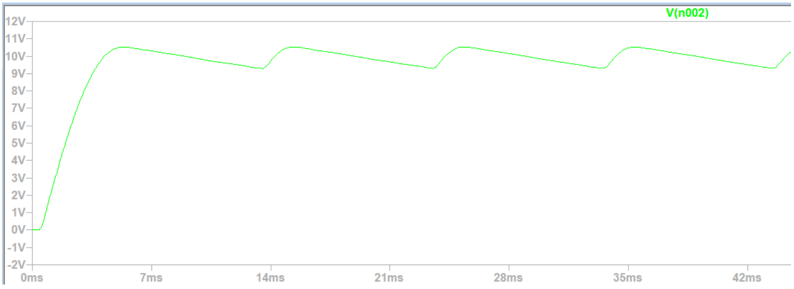
Transformer Secondary Voltage N-Side of Diode:



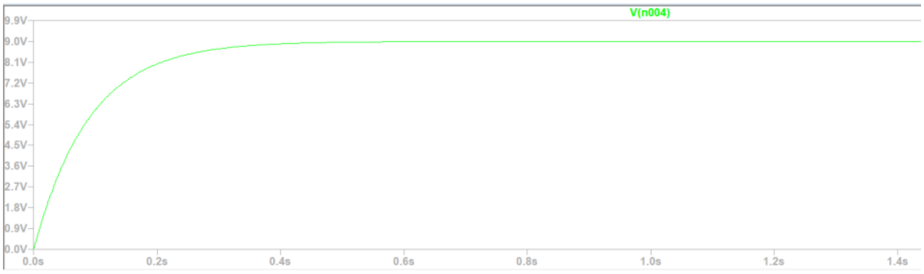
Diode Current:



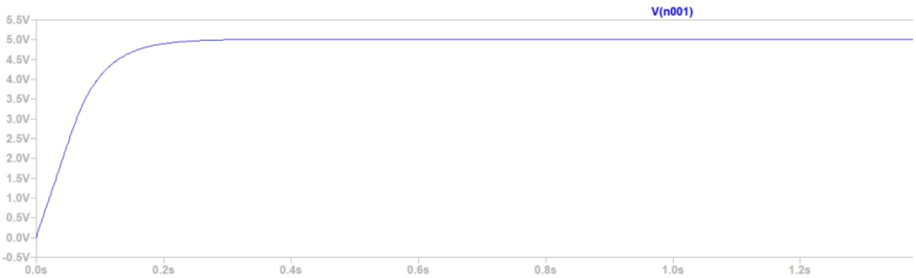
Capacitor Filtered Voltage:



9V Regulated Voltage:



5V Regulated Voltage:



The results from the transient analysis confirm the calculated results, as the waveforms and values for each result closely match the expected results, as the difference in values is small and negligible. E.g The simulated Regulated 5V output is 5.0011V, however this difference does not have a significant effect on the output of the circuit.

Design Evaluation

The design performance of this circuit meets the requirements of the subsystem specifications given in the project outline and would be able to support all subsystems simultaneously.

Conclusion

The DPS designed is an optimised subsystem that meets the requirements of the project specifications. The DPS is driven by the mains wall outlet of the office. The DPS was constructed using a Bridge Full Wave Rectifier, has 4 distinct outputs that can simultaneously power all subsystems, and has an output of 5V at 150mA and 9V at 200mA at each output.

References

-Alonso, G., 2021. *LTspice: Simple Steps for Simulating Transformers | Analog Devices*. [online] Analog.com. Available at: <https://www.analog.com/en/technical-articles/ltspice-basic-steps-for-simulating-transformers.html> [Accessed 26 October 2021].
-N/A, Linear Technology Corporation, "LT3082 200 Single Resistor Low Dropout Linear Regulator", 2009-N/A, Analogue Devices, Inc, " LT1762Series 150mA, Low Noise, LDO, Micropower Regulators",1999-2018