

PSDE6015, Electronic Design Assignment 2018_19

by Emyr Dyer

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HND Electrical & Electronic Engineering

Regulated Power Supplies

PSDE6015 –Electronic Design

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1 EXECUTIVE SUMMARY

This exercise shows the development of a Regulated DC Supply for a Hoist System that utilises a 24V DC Motor. Before development, a specification is written up to list the requirements for the development of the Regulated DC Supply and how it is to be used in a further design outside of the Author's scope of responsibility.

A Design Process is carried out giving justification for component selection, for protective circuits and functional circuits, that are intended to fulfil the specification.

Testing on the Regulated DC Supply is carried out in parts and as a Complete Circuit, with Analysis of the performance on an individual element basis and as a complete unit.

2 RESEARCHING REQUIREMENTS AND COMPILATION OF THE SPECIFICATION

2.1 PERFORMANCE AND OPERATION

The Linear Voltage Supply (REGULATED DC SUPPLY) must deliver 24V DC to a 24V DC Motor used as part of a hoist system to lift a load of 350Kg. To deliver this performance, the REGULATED DC SUPPLY must consistently deliver 24V DC.

As part of the Hoisting System, the REGULATED DC SUPPLY may be used in both indoor and outdoor environments, so temperature ranges will vary from hot to cold. Due to the possible outdoor use, consideration will be given to humid and wet environments. Worst case scenarios of heat and wet environments will be considered. The REGULATED DC SUPPLY will be mounted in a panel, along with the controls for the system to protect from environmental conditions stated previously as well as protection from dirt and corrosive substances.

The REGULATED DC SUPPLY must not overheat and produce as little wasted heat energy as possible. No noxious pollutants will be produced during operation.

For protection from Heat, the system will need a suitable heatsink to allow dissipation of heat produced and applied to the REGULATED DC SUPPLY. A suitable fan assisted air intake and outtake, in conjunction with the heatsink should also be used.

2.2 POWER

The REGULATED DC SUPPLY will be supplied with at least 120V DC from a 230V AC Mains Supply for the conversion to 24V DC.

2.3 SERVICE LIFE AND SHELF LIFE

In use, the REGULATED DC SUPPLY should have a service life equivalent to the rest of the Hoist System, however, to verify the lifespan of the REGULATED DC SUPPLY, trial testing would need to be conducted to determine point of failure.

The REGULATED DC SUPPLY as a spare part should have a minimum Shelf Life of at least 10 Years, long enough to be available for the Hoist System's Technician to facilitate a speedy repair after a fault. To ensure a viable Shelf Life of the REGULATED DC SUPPLY, packaging used to store the part, must protect against moisture, corrosive substances and physical impact.

2.4 MAINTENANCE AND SAFETY

To prevent misuse, connectors on the REGULATED DC SUPPLY will be clearly marked, to aid in system assembly. Operator hazards can include shock is maintenance is carried out before de-energizing and locking out the Hoist System, so appropriate hazard warnings on both the device and documentation must be included. Maintenance of the REGULATED DC SUPPLY should be possible with a competent technician provide parts and schematic are available.

2.5 DESIGN OWNERSHIP

The Design rights are property of the Hoist System designer.

3 DESIGN METHOD, CHOICES AND CALCULATIONS

The way that the Regulated DC Supply is designed, is that a Top Down Design is followed by proceeding in a step-by step manner, ensuring that one element functions as intended before moving on. The first step is to ensure a viable means of protecting hardware and users is put in place, then the other aspects of the design are approached such as how power is delivered, and the thermal protection. The Five core stages of a Power Supply Unit, that influence the design method is AC in, Stepping Down, AC to DC, Smoothing of DC, regulation, and then DC out.

3.1 SHORT CIRCUIT PROTECTION

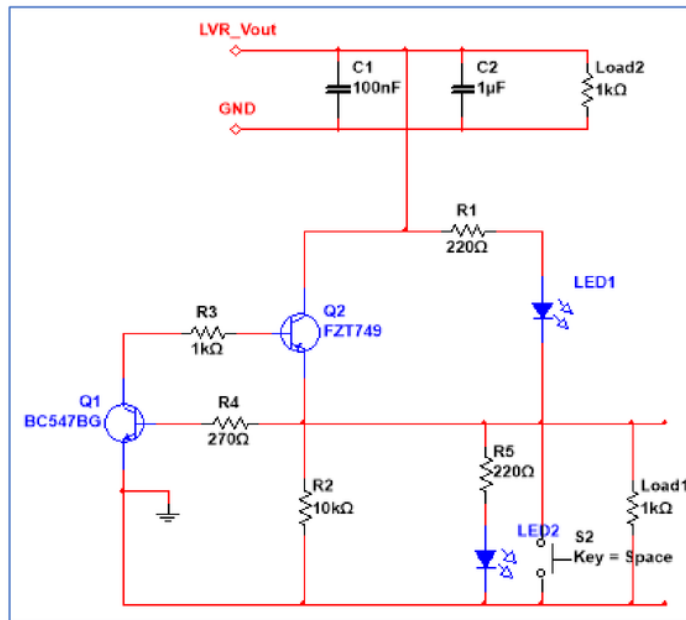


Figure 3-1 Short Circuit Protection

In the design above, a BD140 is recommended, however due to the unavailability in Multisim, a substitution of the FZT749TA (Diodes Incorporated, 2015) is implemented instead.

When the DC output from the Regulated DC Supply is detected, the transistor BC547 (Fairchild Semiconductor, 1997) will then conduct via LED1 and resistors R1 and R4, then transistor FZT749TA will operate, which results in output being delivered to the Load 1 terminal as well as Load 2 being uninterrupted.

When Load 1 is shorted out, the BC547's base is grounded which also cuts off FZT749TA and LED1 goes dark, while the red LED2 illuminates, indicating a short fault. As Load 1 is short circuiting, capacitors C1 and C2 absorb the residual voltage, protecting Load 2. The normally open pushbutton is used to reset the Short Circuit Protection (Analog Devices Inc., Engineering, 2011).

3.2 OVERVOLTAGE PROTECTION

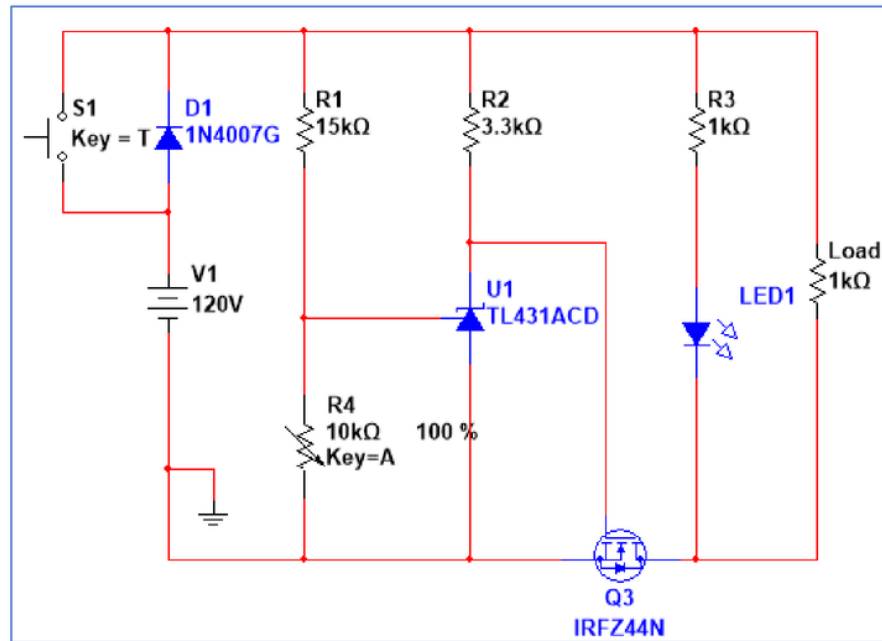


Figure 3-2 Overvoltage Protection

The circuit shown in Figure 3-2 is suggested for the protection of the Regulated DC Supply where the Load in the Circuit is the Regulated DC Supply itself. The MOSFET in the design is in series with the load, and with the gate always being driven, the drain and source will remain in a conduction state provided that pin1 of the TL431 adjustable shunt regulator is receiving a voltage level lower than the voltage reference. When the voltage applied to pin1 is greater than the reference, the gate of the MOSFET will no longer be driven, and the conduction will drop out due to the drain and source opening, resulting in power to the load being cut (Hasse, 2000).

3.3 LINEAR REGULATOR DESIGN

To design the Linear Regulator Design, On Semiconductor's Linear & Switching Voltage Regulator Handbook (ON Semiconductor, 2002) The configuration for the MC1723C, selected for the task was the NPN boost form which would be able to deliver the required 24V DC. The Multisim equivalent of the Regulator IC is the LM723CN (Texas Instruments, 2013), which will be used for this design. The reason for using this configuration, is the larger output provided by the configuration.

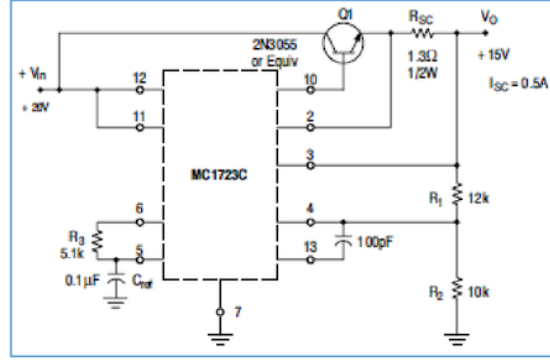


Figure 3-3 NPN Boost

3.3.1 Initial Values

The following components have been selected for the design;

$$C_{ref} = 100pF$$

$$R_1 \text{ and } R_2 \approx 20.1K\Omega$$

$$R_2 \approx \frac{7.0V}{V_o} \times (R_1 + R_2) = \frac{7}{24} \times (20.1 \times 10^3) = 5.86K\Omega$$

$$R_1 = (20.1 \times 10^3) - R_2 = (20.1 \times 10^3) - (5.86 \times 10^3) = 14.24K\Omega$$

$$R_{SC} \approx \frac{0.6V}{I_{SC}} = \frac{0.6}{1.0} = 0.6\Omega$$

$$R_3 = R_1 || R_2 \approx 5.1K\Omega$$

The selection of the previous component values helped to get the design rolling. These values were used to determine other later design choices to be made. Some of the values are just typical values that have been shown to be reliable such as the 7V nominator used to determine R_2 . The element known as R_{SC} is selected to set the Sensing Current capability of the design.

3.3.2 Input Voltage

Referring to the datasheet for the LM723CN, the Voltage limits for the chip were identified. Knowing the desired Voltage Output of the design, the other Voltage drops in the circuit could be accounted for to ensure the correct output.

$$9.5V \leq V_{in} \leq 40V \text{ and } (V_{in} - V_o) \geq 3.0V$$

$$(V_{in} - V_o) = [V_{in} - (V_o + 2\Phi)] \geq 3.0V, \text{ where } \Phi = V_{BEon} \approx 0.6V$$

$$V_{in} \geq V_o + 2\Phi + 3.0V = 24 + 1.2 + 3$$

$$V_{in} \geq 28.2$$

This satisfies the requirement for a minimum V_{in} of 24V. To simplify the design of the input supply, V_{in} is chosen to be 30V and up to 40V at no load.

3.3.3 Selection of Series Pass Element

To determine the Transistor to be used with the design the following factors are considered to make certain the reliability of the chosen Transistor.

$$V_{CEO} \geq V_{in(max)} = 25V$$

$$I_{C(max)} \geq I_{SC} = 1A$$

$$hfe > \frac{I_{SC}}{I_O} @ V_{CE} = V_{in} - V_O - \Phi = V_{BE_{on}} \approx 0.6V$$

$$\therefore hfe \geq V_{CE} = 5V, I_C = 1A$$

$$P_{D(max)} \geq V_{in} \times I_{SC}$$

$$\therefore P_{D(max)} \geq 16W$$

$$\theta_{JC} = 1.52^\circ C/W$$

With these characteristics in mind, the most suitable Transistor to use in the design was the 2N3055AG NPN Transistor, which fortunately also has the benefit of being available for use in Multisim, for the later Simulation and Testing. The $P_{D(max)}$ was also used later to determine the type of Heatsink used.

3.3.4 Input Supply AC to DC

To create a useable 24V DC supply for the DC motor, the supplied 230AC is stepped down using a Full-Wave Bridge Rectifier, the specifications for which is defined as follows;

$$V_{C(DC)} = 30V$$

$$V_{Ripple(pp)} = 3V$$

$$V_m = 40V$$

$$I_O = 1.0A$$

$$f = 50Hz$$

$$r_f = \frac{V_{Ripple(pp)}}{2\sqrt{2}V_{C(DC)}} \times 100\%$$

$$r_f = \frac{3}{2\sqrt{2} \times 30} \times 100\% = 3.54\%$$

$$\omega CR_L \cong 12 \text{ to } 25$$

Using $\omega CR_L = 20$, R_S/R_L is found from using the Schade curves in Figure 3-4 and Figure 3-5.

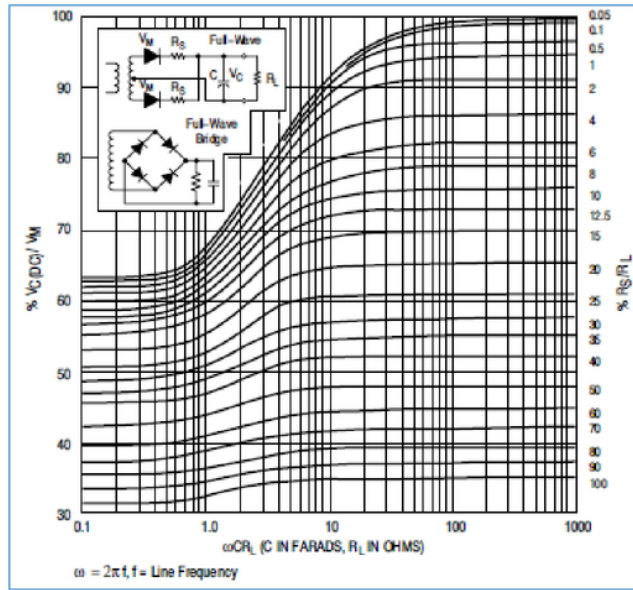


Figure 3-4 Curve 1

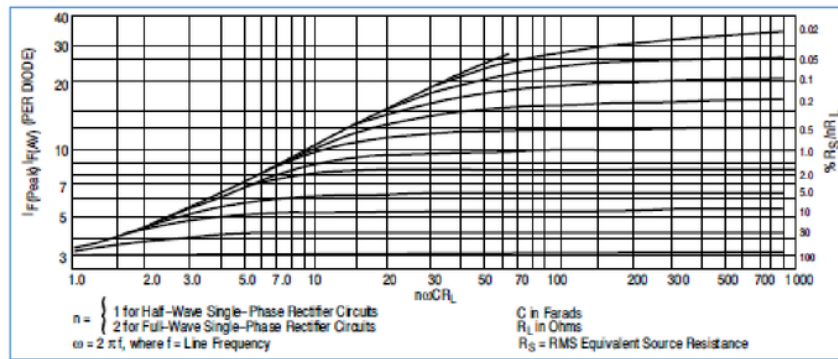


Figure 3-5 Curve 2

$$\frac{V_{C(DC)}}{V_M} = \frac{30}{40} = 0.75 = 75\%$$

$$\frac{R_S}{R_L} = 6\% \text{ or } R_S = 0.06 \times R_L = 0.06 \left(\frac{V_{C(DC)}}{I_O} \right) = 0.06(30)$$

$$R_S = 1.8\Omega$$

The filter capacitor size is found:

$$C = \frac{\omega CR_L}{2\pi f_s \left(\frac{V_{C(DC)}}{I_O} \right)} = \frac{20}{2\pi(50)30} = 2122.07\mu F$$

The rectifier requirements may now be determined:

$$I_{F(avg)} = \frac{I_O}{2} = 0.5A$$

$$I_{F(rms)} = 2 \times I_{F(avg)} = 1A$$

$$I_{F(peak)} = 5.2 \times I_{F(avg)} = 2.6A$$

$$PIV = V_M$$

$$I_{surge} = \frac{V_M}{R_s + ESR} \cong \frac{40}{1.8 + Low\ ESR} = \frac{40}{1.8} = 22.22A$$

The transformer should have the following ratings

$$V_{secondary} = \frac{\{V_M + n \times 1\}}{\sqrt{2}} = \frac{40 + 2}{\sqrt{2}} = 29.7V \text{ or } 30V_{rms}$$

Secondary Resistance should be 1.8Ω

$$\text{Secondary RMS current; } \sqrt{2} \times I_{rms} = 1.41A$$

$$\text{VA Rating Transformer; } V_{secondary} \times I_{rms} \times \sqrt{2} = 30 \times 1 \times \sqrt{2} = 42.33VA \text{ (Minimum)}$$

The values found through the previous calculations helped to inform that the Input Supply would need to, in stepping down the voltage would require a 2:1 turns ratio, to bring the Voltage level down enough to a sensible level that the Linear Regulator could function correctly. The design would also need to be Full Wave Bridge Rectified DC

3.3.5 Heatsink Calculations

To determine the type of heatsink to be used with the 2N3055AG NPN, to maintain a relatively cool running state, the following calculations are carried out:

$$T_j = T_A + P_D \times \theta_{TA}$$

The elements from the previous equation include Power Dissipated (P_D) Ambient Air Temperature (T_A) and (θ_{JA}) the junction-to-ambient air thermal resistance. The θ_{JA} is a sum of the characteristics found in the datasheet for the 2N3055AG.

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}$$

Solving for θ_{SA} ;

$$\theta_{SA} \left(\frac{T_j - T_A}{P_D} \right) - (\theta_{JC} + \theta_{CS})$$

From the datasheet, the maximum Junction Temperature (T_j) for the 2N3055AG is stated to be $+125^\circ C$, so;

$$T_{j(max)} = +200^\circ C$$

An ambient temperature, $T_{A(max)} = +180^\circ C$.

In consulting the datasheet, the $P_D = 0.65W$, and $\theta_{JC} = 1.52^\circ C/W$.

Using Table 3-1, $\theta_{CS} = 0.46^\circ C/W$ as the case used for the 2N3055AG is the TO-204.

Case	θ_{cs}			
	Metal-to-Metal*		Using an Insulator*	
	Dry	With Heatsink Compound	With Heatsink Compound	Type
TO-204	0.5°C/W	0.1°C/W	0.36°C/W 0.28°C/W	3 mil MICA Anodized Aluminum
TO-220	1.2°C/W	1.0°C/W	1.6°C/W	2 mil MICA

*Typical values; heatsink surface should be free of oxidation, paint, and anodization

Table 3-1 Mountings for Packages

$$\theta_{SA} = \frac{T_J - T_A}{P_D} - \theta_{CS} - \theta_{JC}$$

$$\theta_{SA} = \frac{200 - 180}{16V \times 1A} - 0.36 - 1.52 = 6.245^\circ C/W$$

Fitting into the range of 20 to 30 for θ_{SA} , the Wakefield 690 heatsink after consulting both the On Semiconductor and another reference book (Lenk, 2013). With this identified, the Heatsink would be ordered from the manufacturer Wakefield Vette where the price of the component may be quoted, and if too costly, and alternative heatsink that functions to the same standard may be found.

To ensure satisfactory cooling of the Regulated DC Supply, a suitable cooling method in addition to the heatsink should be implemented, such as a cooling fan for instance, to promote airflow through the heatsink fins as well as cooling the rest of the panel controls where the Regulated DC Supply Y is mounted.

4 TESTING, RESULTS AND ANALYSIS

4.1 THE INPUT SUPPLY

The first element under test was the Input Supply to bring the 230AC Supply down to a manageable 120V, for use by the Linear Voltage Regulator. The Input Supply was simulated separately initially to test that it functions separately, before integrating into one simulation.

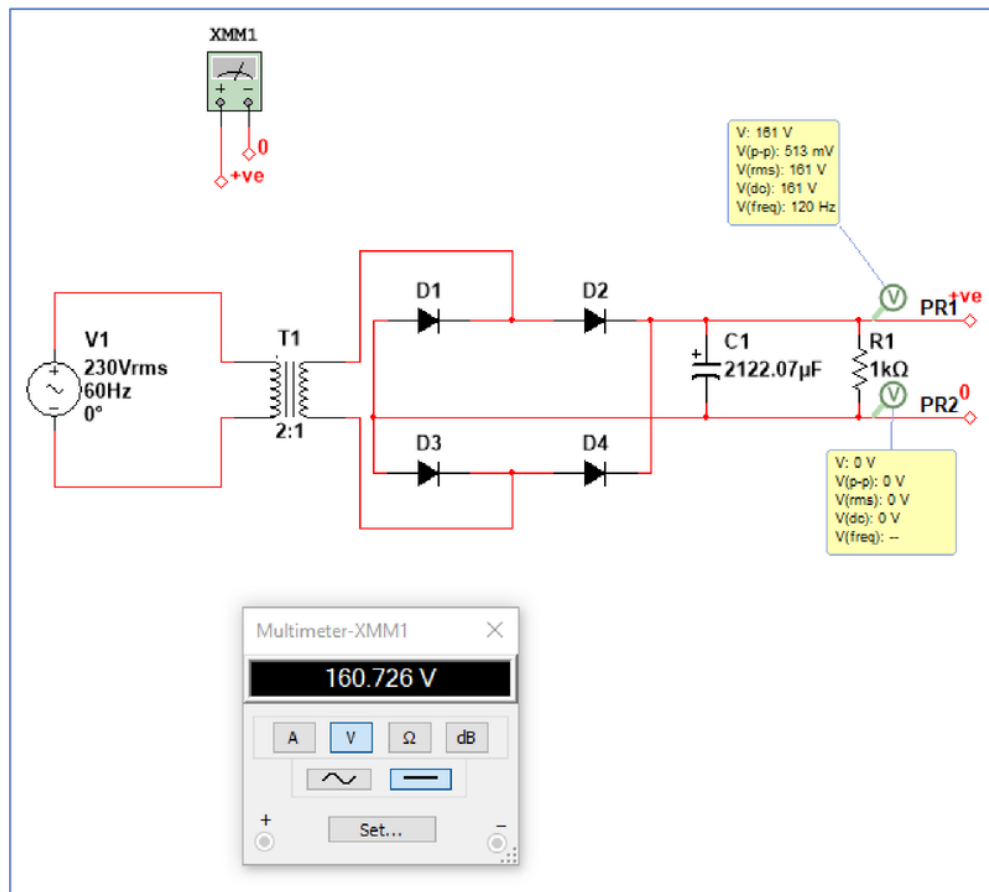


Figure 4-1 Input Supply Simulation

The Input Supply when simulated produced an unexpectedly higher value of DC than anticipated. Many attempts were made to lower the Output DC by adjusting the Turns Ratio of the Transformer, but no satisfactory configuration of the circuit could be found at the time. There was some ripple detectible in the DC output (Figure 4-2), however at this point it was acceptable as the Linear Voltage Regulator design should remedy the ripple.

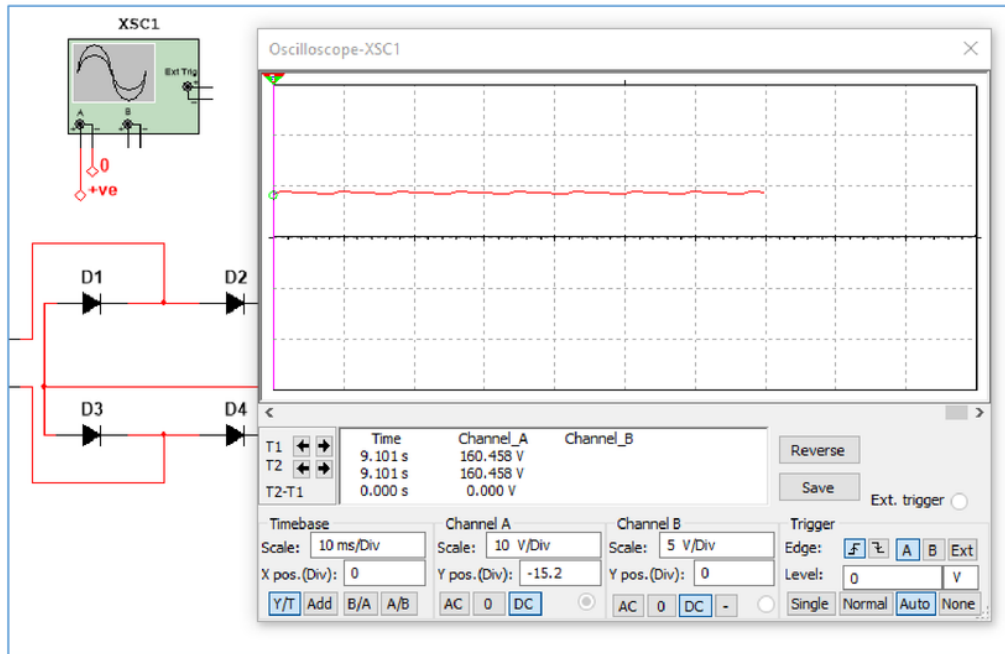


Figure 4-2 Input Supply Output Waveform

4.2 THE LINEAR VOLTAGE REGULATOR

Progressing onto the next step of the Simulation Testing, the Linear Voltage Regulator's input was modified to the original planned 120V DC to the approximate output of 161V DC from the previous Simulation.

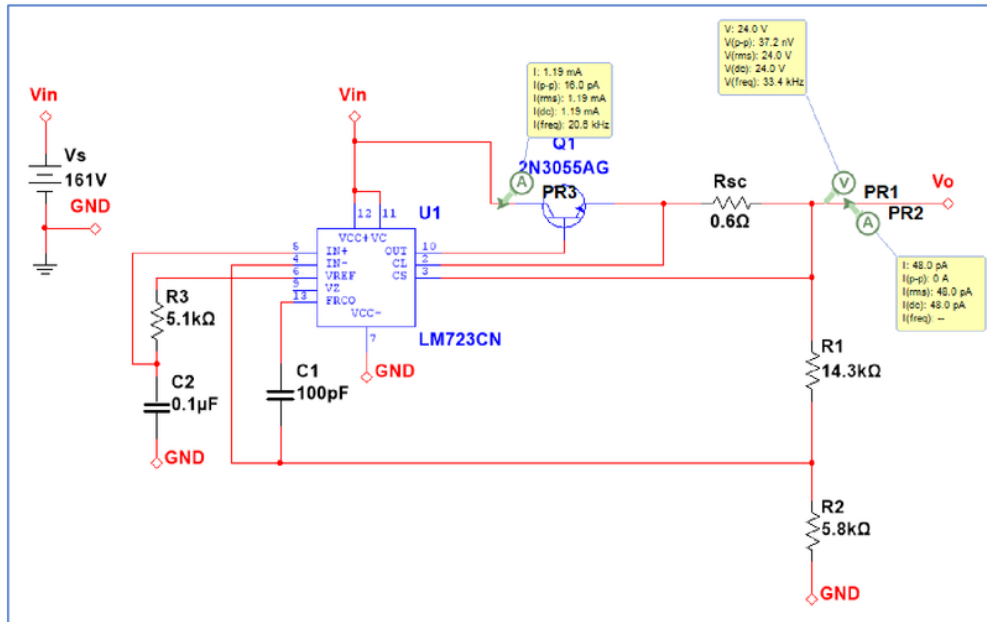


Figure 4-3 Linear Voltage Regulator Simulation

In spite of the higher than anticipated Input Voltage entering the Linear Voltage Regulator, the circuit simulated well by producing a 24V DC output with no registered ripple as can be seen in Figure 4-4, however this is of course based on the ideal input conditions being produced. The final Simulation would be of both The Input Supply and the Linear Voltage Regulator running together.

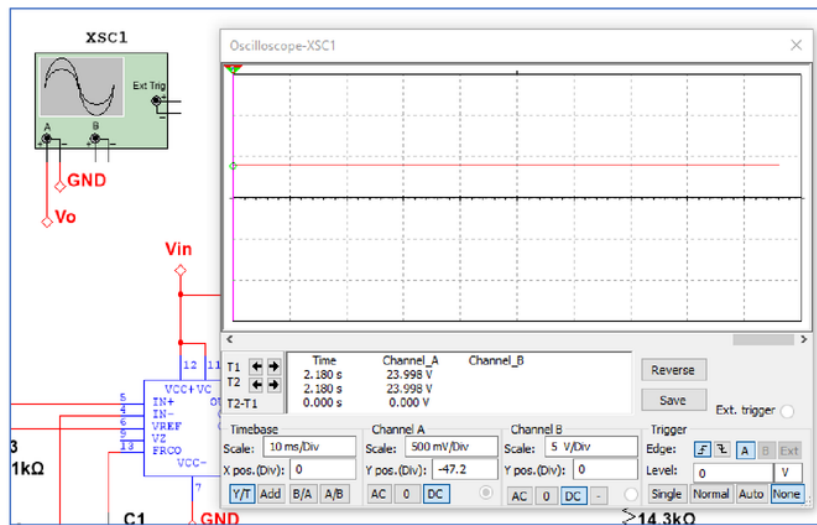


Figure 4-4 LVR Waveform

4.3 BOTH CIRCUITS

Both the Input Supply and Linear Voltage Regulator were combined using On Page Connectors. The only alteration being the removal of the 161V DC battery source as well as the addition of another Voltmeter to the Simulation.

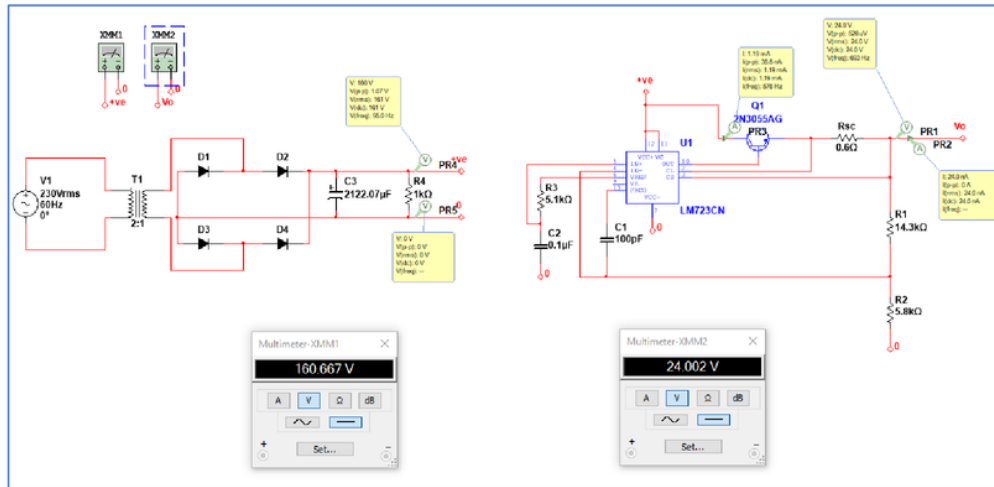


Figure 4-5 Two Circuit Simulation

While the supply maintains a visible ripple at around 160V DC, the Linear Voltage Regulator performed well by producing the desired 12V DC Output with on ripple at all, as can be seen in Figure 4-6 where the middle sinusoidal waveform is the 230V AC supply, the bottom waveform is the Rectified DC with ripple, and the top waveform being the smooth 24V DC output.

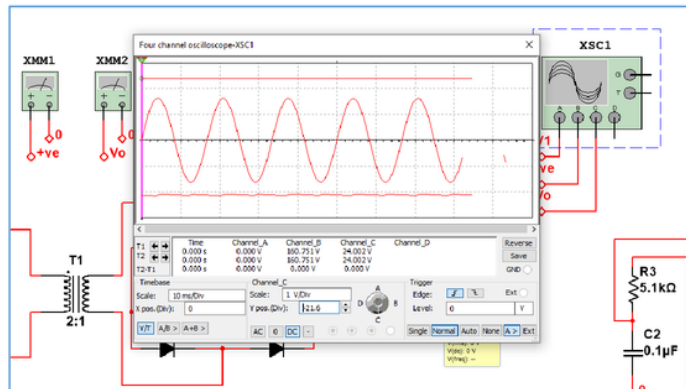


Figure 4-6 AC, Rectified and Regulated Waveforms

4.4 ANALYSIS

While it is true, that not all elements performed as expected, particularly the AC Input Supply, the Linear Voltage Regulator performed exactly as intended, producing the required 24V DC Output as specified in the Specification. The pertinent issue with this Simulation was that there was no means to simulate and test the performance of a heatsink on the Transistor within the Regulator Design. It is suspected that with the higher output DC from the Supply Rectification, there will be other consequences, however without a physical test of the whole circuit, only speculation remains.

5 CONCLUSIONS

While there was slight deviation in result for spec regarding the Input Supply converting to the correct Voltage level of DC, the overall result of the Design was successful. The biggest strength of the design was the relatively precise output Voltage, as the unvarying 24V was a significant requirement for driving the motor for the Hoist System. The most significant weakness in the Analysis of the system, was that without building the circuit itself, there was no foreseeable way to test the viability of the heatsink selection made for the Transistor in the Linear Voltage Regulator design.

In terms of improvement to the exercise of developing a Regulated DC Supply, would be to carry out a practical build, to not only test the heatsink, but also to build a few prototypes to determine the point of failure for the circuit if possible, within a reasonable time.

A full test of the Regulated DC Supply, through practical build should have been considered using perhaps a scaled version of the Hoist System, to determine if design was sound in principle. While an attempt to test a virtual motor with the Regulated DC Supply was made in Multisim, no appreciable observations could be made, possibly due to limitations with Multisim.

A costing analysis should have been carried out to determine the unit cost to the customer for whom the Regulated DC Supply is being developed for, as they will want to consider other solutions that are more cost effective.

Implementing the overvoltage and short circuit design into both the simulation and a practical build would have been a worthwhile endeavour to determine the viability of their design as well as finding out if the design is cost effective in comparison to buying off the shelf solutions.

6 WORKS CITED

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PSDE6015, Electronic Design Assignment 2018_19

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

55/100

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GRADING FORM: ASSIGNMENT RUBRIC 2018

EMYR DYER**55****ENGAGEMENT WITH LITERATURE**

There was evidence of further reading and research and some in text referencing. Your references were mainly appropriate to the task, however the reference list was short and you should increase the breadth of your research for future assignments. There was a heavy reliance on information gained from the course notes.

5**KNOWLEDGE AND UNDERSTANDING**

The knowledge and understanding of the subject demonstrated by this assignment was reasonably detailed and mainly accurate. There were very few gaps in your knowledge of the basic concepts and your understanding of the higher level concepts was demonstrated to a limited degree - you could have explained in more detail how the circuit evolved. Further work – Your explanations need to be more detailed and written with a greater emphasis on critical evaluation rather than description.

18

COGNITIVE AND INTELLECTUAL

 Your analysis of the task was generally satisfactory, both in class and as shown in this assignment, however it did tend more towards descriptive rather than analytical. You have demonstrated some analytical skills and your approach to the task was logical. You wrote a short conclusion that demonstrated some skills in analysing quantitative and qualitative data, however this was generally basic in nature. Further work – in your conclusion, you should relate the results to the original specification and to accepted theory and provide a detailed critical analysis of this.

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PRACTICAL APPLICATION

 Your application of practical skills for this task was generally very good. You used the resources appropriately when designing the circuit and you used appropriate options for testing and evaluating the circuit performance. You managed to design an effective circuit that functioned within the specification and achieved this by only asking for assistance when appropriate thus demonstrating some advanced problem solving skills. Your results were comprehensive and allowed for a detailed conclusion to be attempted.

14

TRANSFERABLE SKILLS FOR LIFE

 In this assignment you have demonstrated skills in working individually and also collaboratively. Your

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written report was generally good and contained most of the required detail, it was also written in a coherent and logical way. The available word count was in the main effectively used.