

APPLICATION NOTE:

SWITCH-MODE POWER SUPPLY: CONSTANT VOLTAGE, CONSTANT CURRENT, AND CONSTANT POWER

EXECUTIVE SUMMARY

Astrodyne TDI's wide range of Switch Mode Power Supplies (SMPS) is used in several markets, each with its requirements. Our power supplies come equipped with the ability to control their output characteristics based on either voltage, current, or power, depending on the application. Our power supplies offer the ability to switch between the three modes seamlessly. This article explains the difference between constant voltage, constant current, and constant power and some of the applications that may require them. After looking at each, we will dive into how Astrodyne TDI implements these features in each of our programmable supplies.



CONSTANT VOLTAGE MODE IN POWER SUPPLIES

Constant Voltage (CV) is the standard operating mode when it comes to power supplies. In Constant Voltage Mode, a power supply will output a set voltage across its entire load range. Figure 1 depicts a graph of Voltage vs. Load Resistance for a power supply programmed to 48V with a current limit of 80A. Note how the voltage remains constant from no load to full load.

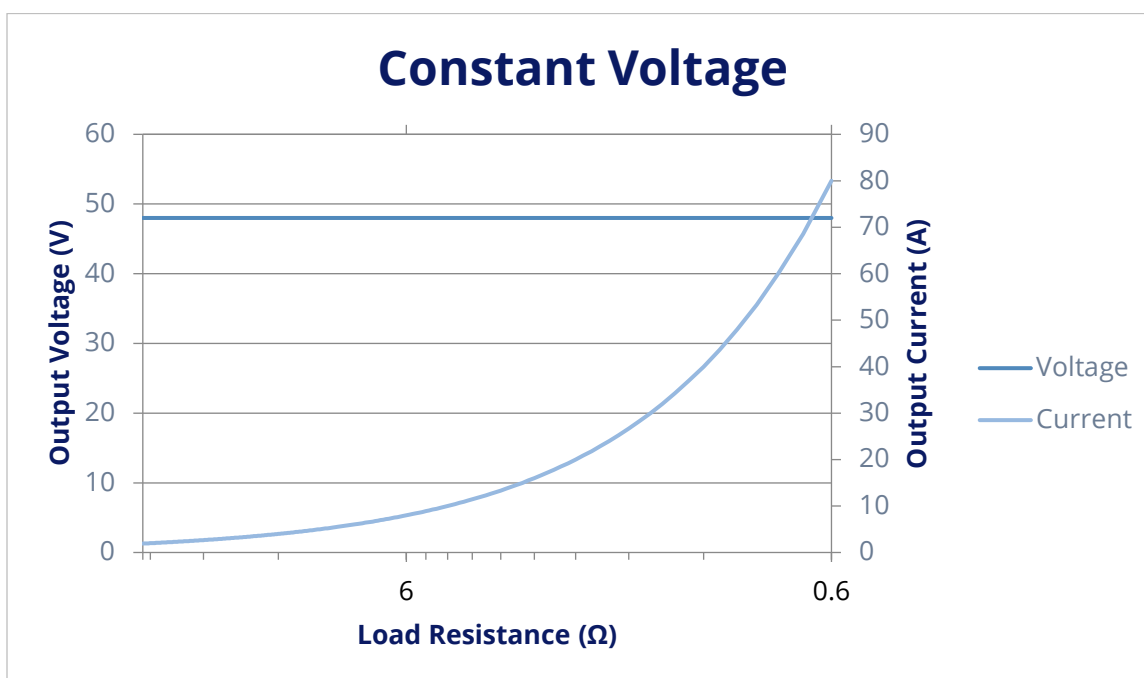
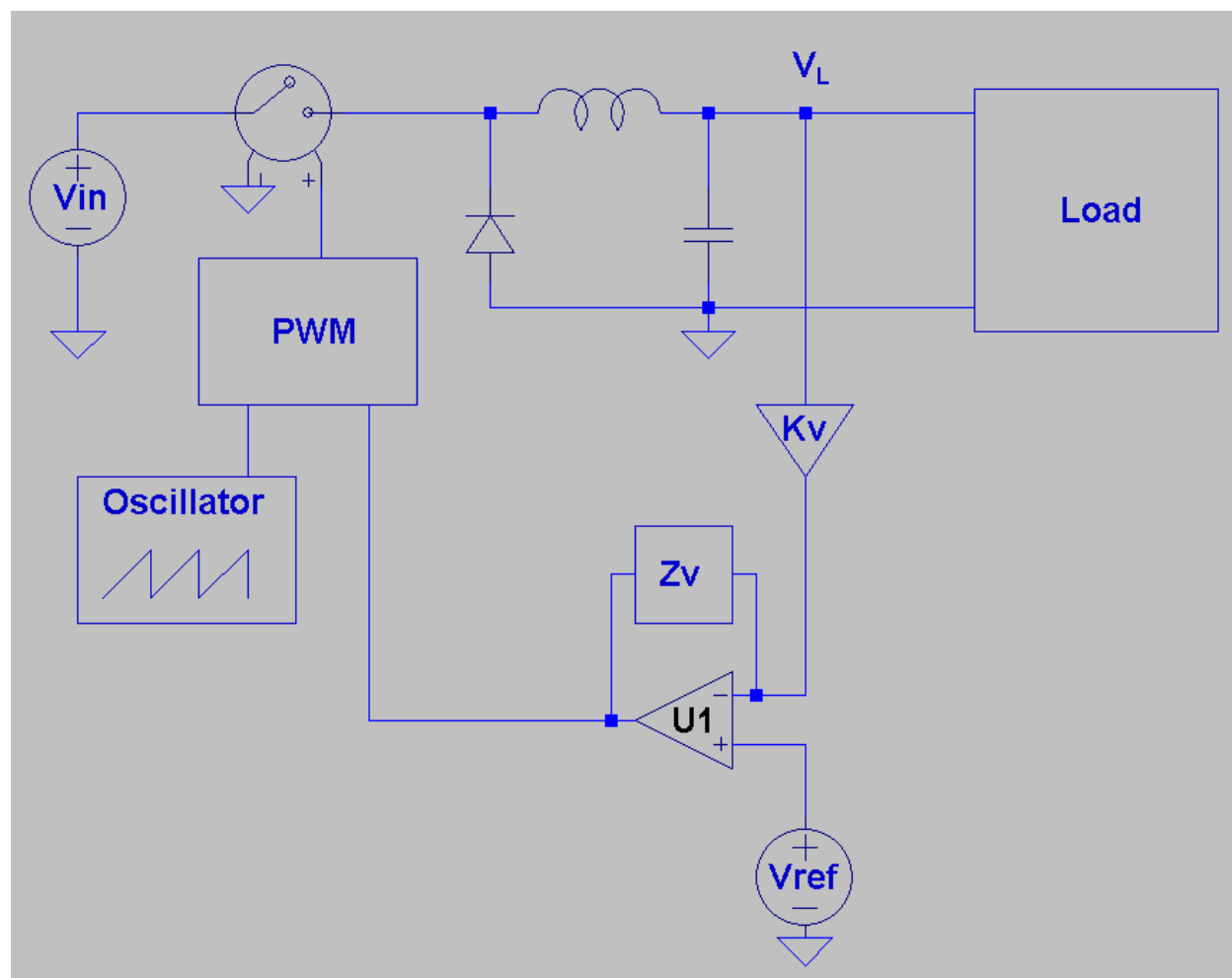


Figure 1 – Constant Voltage Output

For an SMPS to regulate at some set voltage across changing conditions, it needs a control loop. A simplified control loop for a buck converter is shown in Figure 2, although these principles will apply to any topology.

**Figure 2 – Voltage Control Loop**

The control loop is made up of several parts. A scaled representation of the converter's output voltage is compared against a voltage reference through the circuit U1 known as an Error Amplifier (EA). As the name implies, the Error Amplifier outputs a signal that corresponds to the deviation of the output voltage from the reference V_{ref} . If the output voltage is higher than the reference the Error Amplifier will decrease the voltage on its output accordingly. In the case where the load increases and the output voltage begins to fall below the reference, the Error

Amplifier will increase its output voltage. When the scaled output voltage is equal to the reference, equilibrium has been reached, and the EA keeps its output constant.

Afterward, the EA signal is compared against a ramp waveform to create PWM pulses for the top switch in a standard buck converter, or as a control signal in more complex topologies. Controlling the width of these pulses is what allows designers to control the output voltage of the converter. Wider pulses equate to more energy delivered during each switching cycle, which in turn increases the energy delivered to the load to keep the output voltage constant. As seen in Figure 3, the higher the signal coming from the error amplifier, the wider the PWM pulses become. Intuitively, this means that as the output voltage falls, the converter needs to deliver more energy per switching period to return to equilibrium.

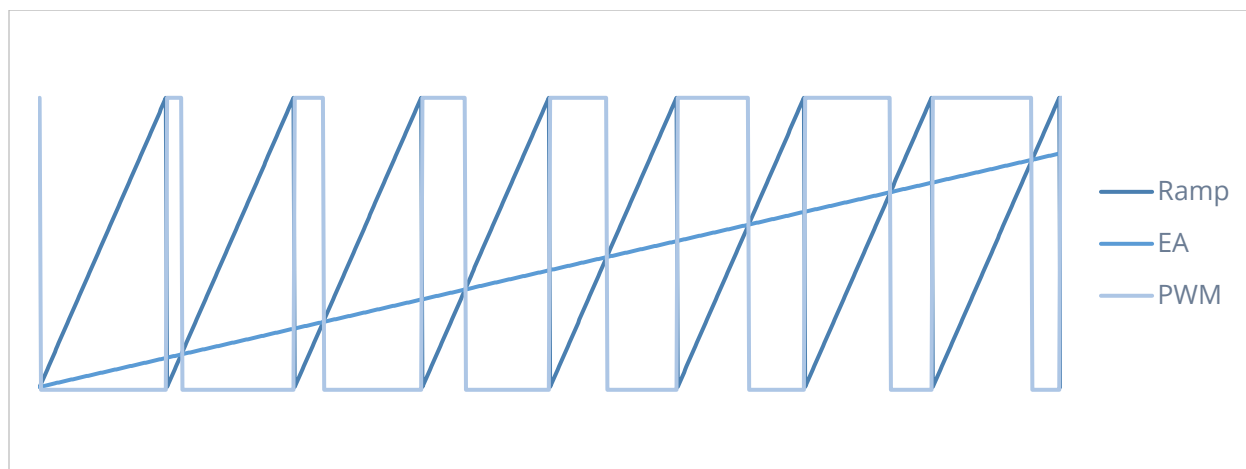


Figure 3 – Error Amplifier vs. PWM

CONSTANT CURRENT MODE IN POWER SUPPLIES

The Constant Current (CC) operating mode can be viewed as a parallel to the aforementioned Constant Voltage operating mode. The goal of Constant Current Mode in power supplies is to maintain a set current output over changing load conditions. In Figure 4, the same 48V converter is programmed with a constant current setpoint of 24A. At a 2Ω load resistance, the output voltage is 48V and will decrease with load resistance to maintain a 24A output current.

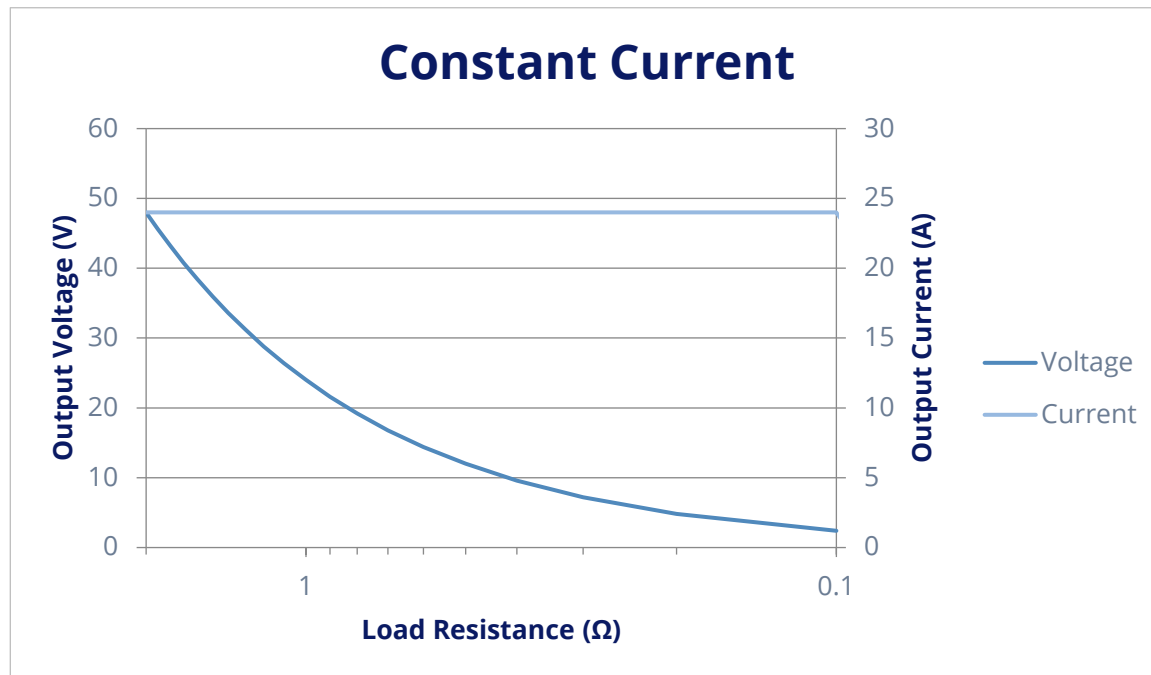


Figure 4 – Constant Current Output

Continuing with our previous buck converter example, the circuit shown for constant voltage can be modified slightly to instead regulate based on current. The resulting circuit is shown in Figure 5:

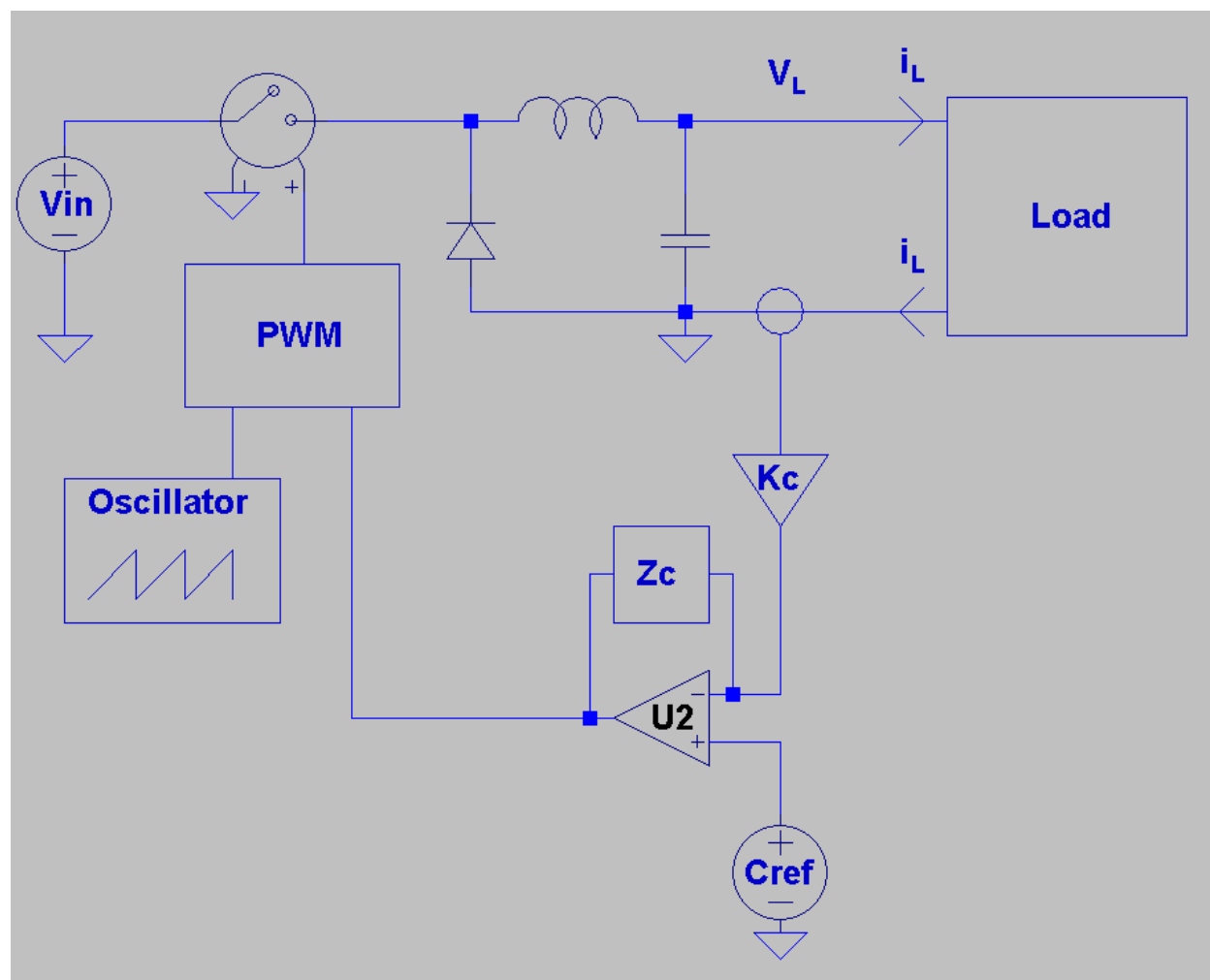


Figure 5 – Current Control Loop

In place of the scaled output voltage, a power supply operating in CC mode will compare its reference against the scaled output current. This can be accomplished through the use of a hall effect sensor, a shunt with a differential amplifier, or any other current to voltage conversion method. In this example, the converter will still modify the output voltage, but will now adjust the output voltage to maintain the desired current.

When only running with constant current, having a light load, or no load, will cause the converter to reach the maximum duty cycle. At light loads (high resistance), the voltage would have to be greater than the maximum voltage of the supply to output the programmed current. Conversely, having a high load (low resistance) will

The diagram illustrates a closed-loop current-mode control system for a buck converter. The power stage consists of an input voltage source V_{in} , a MOSFET switch driven by a PWM signal, a freewheeling diode, an inductor, and a load. The load voltage is V_L and the load current is i_L . The control system includes an oscillator providing a sawtooth reference, a minimum selector $\text{MIN}(A, B)$ that compares the reference with the load current feedback, and two comparators $U1$ and $U2$. Feedback signals are derived from the load voltage V_L (via gain K_v and integrator Z_v) and the load current i_L (via gain K_c and integrator Z_c). These signals are compared with reference voltages V_{ref} and C_{ref} to generate the PWM signal.

Figure 6 – Voltage and Current Control Loop

With separate references, the current and voltage setpoints can be individually adjusted. This allows the converter to specify a maximum voltage while allowing the current loop to stay in control until that maximum voltage is reached.

Now when there is a light load condition, the voltage loop can take over and continue to regulate the output. When combining the voltage and current loops, however, only one signal can be used at a time. In this example, the lower of the two signals, i.e. the signal which has exceeded its reference, is used as the input to the PWM block. This prevents either voltage or current from exceeding their programmed limits.

Going back to the previous example, our power supply programmed with a 48V voltage limit and a 24A current limit, a $2\ \Omega$ load resistance is the switching point. At $2\ \Omega$ both the voltage and current loops are satisfied, either of the signals will yield the same output voltage. Above $2\ \Omega$, if the current loop were allowed to remain in control, the voltage would continue to increase above 48V to maintain a 24A output. Below $2\ \Omega$, if the voltage loop were to remain in control, the current would begin to exceed 24A. Astrodyne TDI's line of power supplies can switch between these modes seamlessly.

CONSTANT POWER MODE IN POWER SUPPLIES

So far, we have covered power supplies that can regulate based on current, voltage, or both. To limit the output power, and therefore input power, a third operating mode is introduced: Constant Power (CP). While operating in Constant Power mode, the voltage is controlled such that the output power remains constant. In Figure 7 we keep our original voltage set point of 48V, the current setpoint of 80A, but now program the power set point to 1 kW. For each load resistance shown, the product of the output voltage and current equate to 1kW.

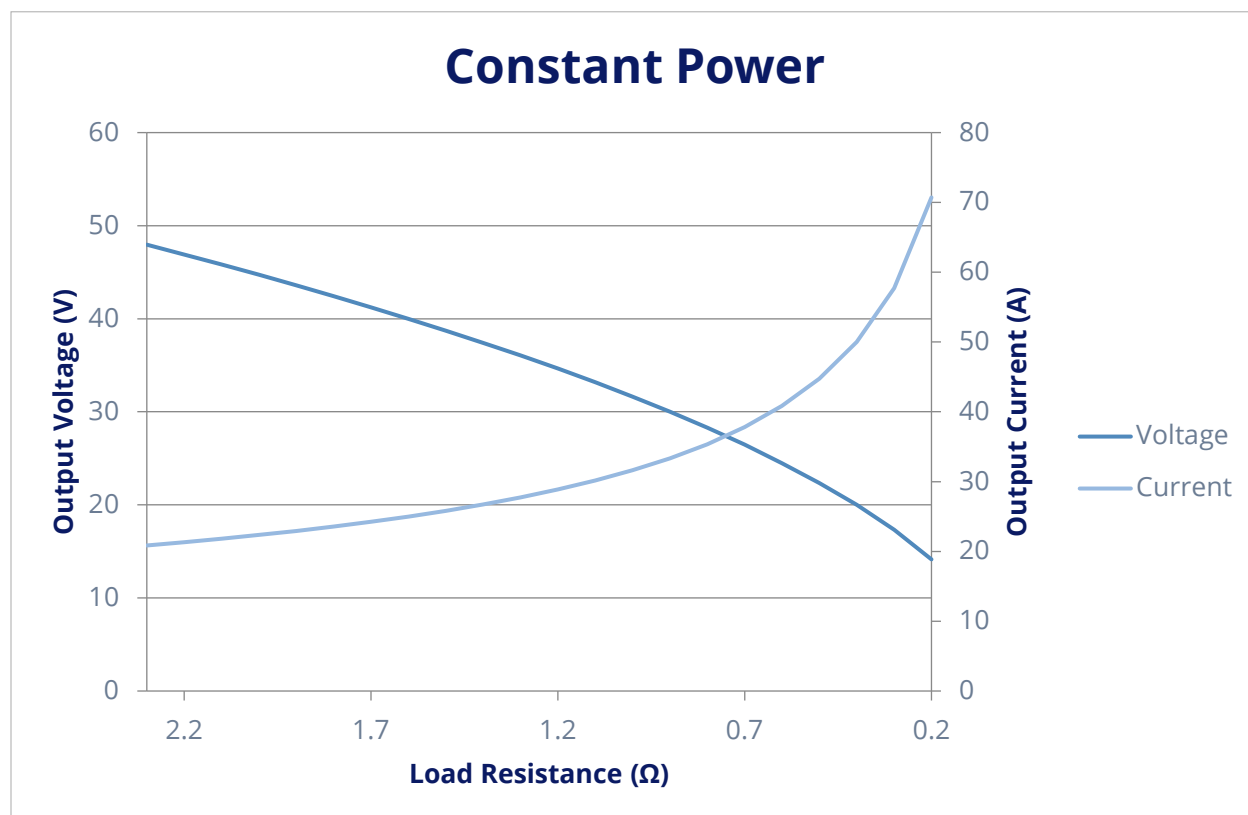


Figure 7 – Constant Power Output

Just as with the constant voltage and constant current operating modes discussed earlier, Constant Power needs its control loop. The scaled representations of voltage and current from the previous examples can be multiplied to give a signal proportional to output power. With this, we can begin to regulate output power as well. Figure 8 shows a full implementation of Constant Voltage, Constant Current, and Constant Power in one.

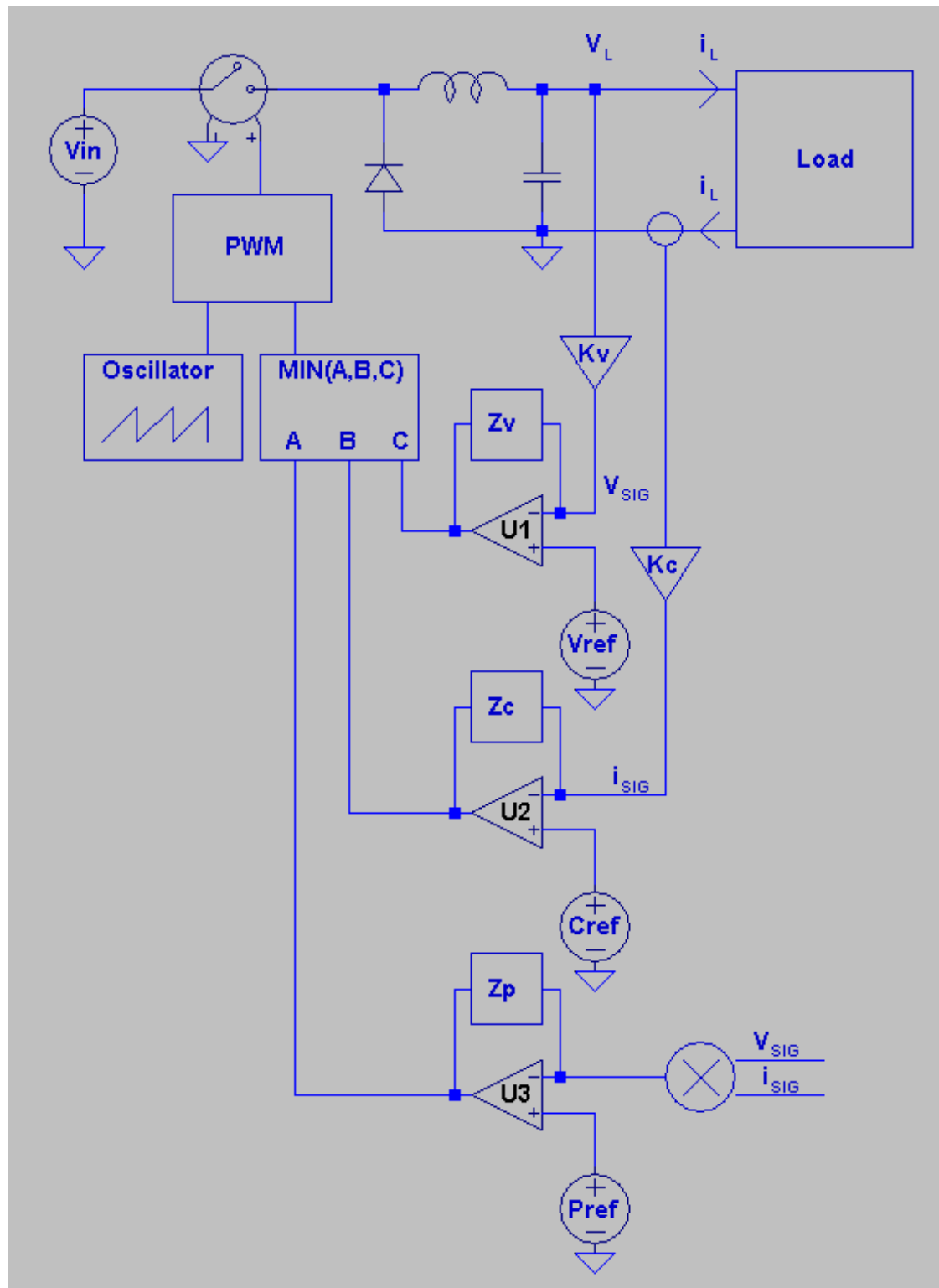


Figure 8 – Voltage, Current, and Power Control Loop

Admittedly, the graphs shown above for the three operating modes do not show the full picture. The horizontal axes for these graphs were selected to highlight the parts of the I-V curves where the desired operating mode was in effect. The circuit is shown above, however, includes all three control loops working together. It is also important to understand how these modes interact.

The graph below shows the voltage curve for a power supply programmed to 48V with a voltage limit of 48V, a current limit of 80A, and a power limit of 2000W across its full load range.

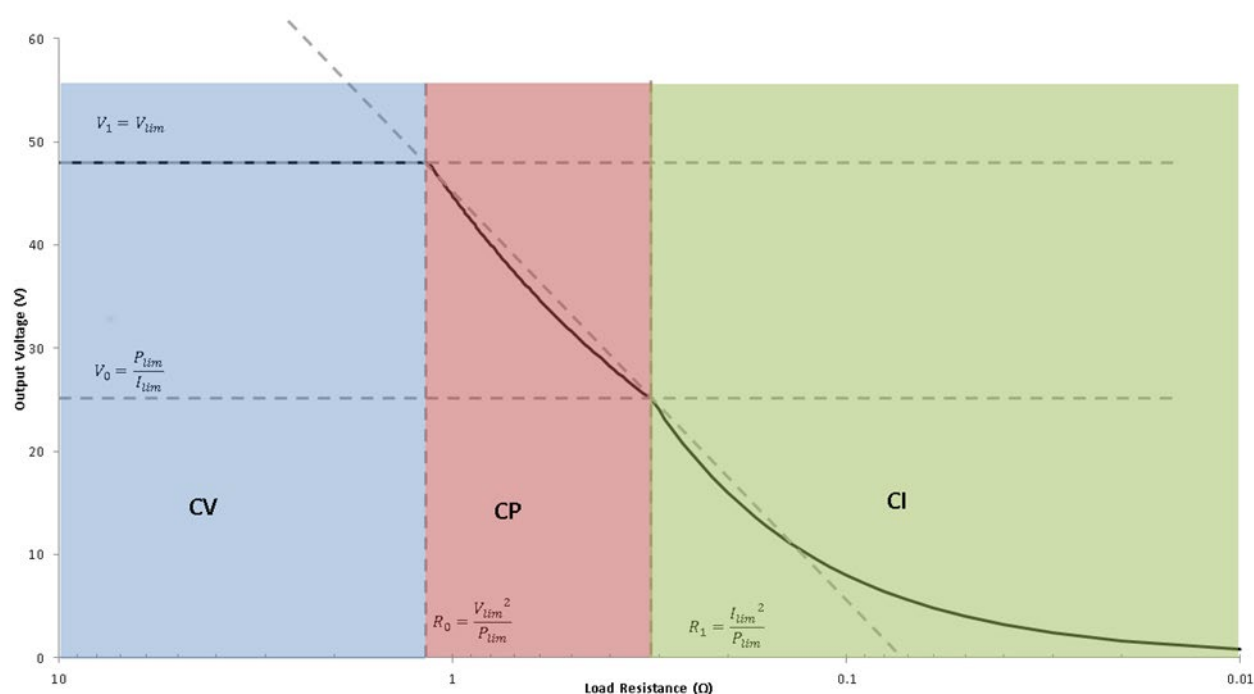


Figure 9 – Full Load Range Output

Figure 9 shows the transition between each of the operating modes based on the load resistance. These transitions are seamless, no setting needs to be altered, no bit needs to be flipped. The shape of the graph can easily be altered by changing each of the setpoints. The values of V_0 , V_1 , R_0 , and R_1 can be moved by changing the voltage limit, V_{lim} , the power limit, P_{lim} , and the current limit I_{lim} . When the load resistance hits R_0 the Power Error Amplifier has the lowest voltage out of the three Error Amplifiers as the power output tries to exceed the power limit. This causes the Error Amplifier's signal to take over the control loop. Similarly, when the

load resistance further decreases to R_1 the current limit is hit and the Current Error Amplifier begins to take over.

SWITCH-MODE POWER SUPPLY APPLICATIONS

CONSTANT VOLTAGE POWER SUPPLY FOR LEDS

Take, for instance, an LED lighting application. An LED's brightness is directly proportional to the amount of current flowing through it, but overdriving an LED can greatly reduce its lifespan. With a constant voltage supply, attempting to run a series string of LEDs would require either a current mirroring circuit, an external current control, or a series resistor. This creates unnecessary losses and increases design complexity.

Take a series string of LEDs being powered from a fixed voltage source and current limited with a series resistor. If one of the LEDs were to fail short, the sum of the forward voltages of the LEDs would decrease and the voltage across the resistor would increase accordingly. This would cause an increase in the current through the string and the power dissipation in the resistor. Higher currents and temperatures would put even more stress on the remaining components, eventually causing a full failure.

With a constant current source, a failed LED would simply cause the converter to lower its output voltage by the forward voltage of the LED. Current would remain the same, power dissipation would decrease, and the remaining LEDs would continue to operate. Constant current sources are continually compensating for load resistance changes due to temperature, component tolerances, and aging.

CONSTANT CURRENT IN CATHODIC PROTECTION

Another use for Astrodyne TDI's constant current sources is Impressed Current Cathodic Protection. Historically, cathodic protection has been accomplished with a step-down transformer tuned to achieve the correct current. Over time, however, not only does the transformer wear out, but the resistance of the target changes. This leads to the need to re-tune the transformer, costing time and man-hours. This is especially difficult in remote locations. With a Mean Time Between Failures of

over 250,000 hours, Astrodyne TDI's constant current sources can cut out hours of dangerous work and will output the same current regardless of changes to the target load.

Further reading on the topic of ICCP can be found in the Astrodyne TDI article: "Successfully Adapting High-Frequency Switch Mode Power Supply Technology to Impressed Current Cathodic Protection"

CONSTANT POWER MODE FOR RESISTIVE HEATING

In applications where accurate power dissipation is needed, Astrodyne TDI's constant power supplies excel. With a standard resistive heating element, there can be a significant change in output power due to the effects of the material's temperature coefficient. The resistance of the heating element will increase with temperature. This effect varies between materials. Some materials can almost double in resistance from the reference temperature (usually 20 °C) to their maximum operating temperature. Other materials like Silicon Carbide exhibit non-linear temperature coefficients, where resistance will decrease before increasing at higher temperatures.

In place of direct temperature measurements at different points within the heated area to approximate the power being delivered, a constant power source will automatically track these changes. This can greatly simplify the setup of the overall system and maintain a higher accuracy than traditional methods.

In systems with more than one element, a mismatch in resistance can cause a large temperature gradient between elements and lead to uneven heating or a damaged element. By using a constant power supply for each element, you can guarantee equal distribution of heat in each element leading to more uniform heating of the target.

ABOUT THE AUTHOR



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Stephen Innis joined Astrodyne TDI in November of 2017 as an Electrical Engineer. He has a technical background in robotics engineering and teaching 3D printing and PCB manufacturing on CNC mills in his local community. Stephen received his B.S. Electrical and Computer Engineering degree at the Rutgers University in Newark, NJ, with a focus on analog circuitry and control theory. Now, as part of the growing Research & Development team, Stephen specializes in fast prototype development and is well versed in Astrodyne TDI's line of power products.

A man with glasses and a lab coat is working in a laboratory. He is holding a small electronic component in his hands. In the background, there are several racks of electronic equipment, including multi-channel electronic loads. The image has a blue tint and a semi-transparent overlay for the text.

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