Power supply HOLD-UP time

Introduction

A warning signal at a time period is often requested from a power supply for the load to complete housekeeping chores before the output voltage drops out of regulation. A circuit to monitor AC input voltage and a bulk capacitor of sufficient size are often used to meet these requirements.

The HOLD-UP time of an off line, high frequency power supply can be defined as the time required for the output voltage to remain within regulation after the AC input voltage is removed. It is commonly expressed in ms from a specific input voltage, which is usually less than the nominal AC input voltage, and at a specific output power. The power supply is designed to regulate output voltage at the DC bulk voltage which is reached after the HOLD-UP time.

If a HOLD-UP time is required, there are tradeoffs with respect to the power supply design input voltage and regarding the size of bulk capacitors. Often the major part of the power supply design, on the primary side, depends on the lowest DC bulk voltage after the HOLD-UP time in which the power supply can operate.

This document presents a comparison between lab data, P-Spice simulation and MathCAD analysis of the same high frequency off line power supply. The power supply is a VIPer53DIP-E demo board with a universal 85 to 264 VAC input voltage and a 12 V output voltage with a 2 A load. The inrush resistor, R1, is 3 Ω and the common mode inductor, L1, is about 2.5 Ω The bulk capacitor, C2, is 68 μF and measures about 60 μF. The requirement is for a 10ms HOLD-UP time, an AC voltage at turn off of 110 V_{AC} and the power supply is designed to operate at an input voltage of 80 V_{DC}.

1 Equation derivation

The equation derivation approach is to determine the minimum bulk voltage with energy equations and then use the energy at this voltage to determine the minimum operating voltage. The symbol for overall efficiency is μ and the efficiency used when the AC line is removed is represented by N_o.

2 MathCAD

MathCAD is used to determine the minimum operating voltage and also to determine the bulk capacitor value for a HOLD-UP time, T_{up}, of 10 ms. *Figure 1* shows the AC input voltage as a blue dashed line and the equivalent DC input voltage in red. Note that for a bulk capacitor of 60 μF (x-axis), the DC voltage is about 80 V (y-axis). A procedure to calculate the bulk DC voltage or the bulk capacitance is given in *Section 6.1.*, *Equation 27* and *Equation 28*.

3 P-SPICE

A P-Spice simulation of a bulk capacitor discharge can be approximated using a voltage controlled current source G1 (see *Figure 2*). Using an effective voltage range from the peak bulk voltage to a minimum operating voltage, a load current can be simulated which is inversely proportional to the bulk DC voltage.

For an example, bulk voltages of 80 to 150 V_{DC} can be monitored from a 110 V_{AC} input voltage turn off with a 10ms HOLD - UP time requirement and a power supply output power of 24 W. The following equations calculate the bulk capacitor current supplied to the power supply at 150 V and 80V for an output power of 24 W and an efficiency of 87%:

Equation 1

$$P_o = 24W \qquad N = 0.87$$

Equation 2

$$P_{in} = \frac{P_o}{N} = \frac{24}{0.87} = 27.6W$$

Equation 3

$$at \quad Vc = 150V \quad I_C = \frac{27.6}{150} = 0.184A$$

Equation 4

$$at \quad Vc = 80V \quad I_C = \frac{27.6}{80} = 0.345A$$

A voltage controlled current source with a 230 V reference can be used with a gain of 0.0023 to simulate the above currents.

A voltage source of 230 V_{DC} when subtracted from the initial bulk voltage gives

230 - 150 = 80 and when subtracted from the final bulk voltage gives 230 -80 = 150. A gain of 0.184 / 80 = 0.0023 and 0.345/150 = 0.0023 satisfies the required currents:

Table 1.   Current simulation

V_{bulk}	V_{bulk} (230 V)	V_{bulk} (230 V) x 0.0023
150	80	0.184
80	150	0.345

The simulation in *Figure 3* is similar to the lab data in *Figure 5* with the DC bulk voltage (green) dropping to about 80 V_{DC} (y-axis) after 10 mS (x-axis 40 to 50 ms) from the low point of the ripple voltage. *Figure 3* also shows the bulk load current (blue) from G1, which is 0.184 A when the bulk voltage is 150 V and 0.345 A when the bulk voltage is 80 V.

4   Lab data

Figure 5, shows the AC input voltage (green) and DC bulk voltage (yellow). The HOLD-UP time begins the measurement at the low level (min. Bulk Voltage) of the ripple voltage (red dashed horizontal line) and after 10 ms the bulk voltage drops to about 80 VDC (red vertical dash-dot line). The measurement begins at that point because the AC input line could be removed when the bulk voltage is at its minimum. Note how the DC bulk voltage decreases more quickly as the DC bulk voltage drops because the power supply current drain increases from the bulk.

5   Equation derivation

● Energy equation for a capacitor (C):

Equation 5

$$E = \frac{1}{2}CV^2$$

Equation 6

$$E = \frac{1}{2}C(V_{b_{pk}}{}^2 - V_{b_{min}}{}^2)$$

● How to calculate the energy in C for each half line cycle:

Equation 7

$$E_{in} = C(V_{b_{pk}}{}^2 - V_{b_{min}}{}^2)$$

Equation 8

$$V_{b_{min}} = \sqrt{\left(V_{b_{pk}}{}^2 - \frac{E_{in}}{C}\right)}$$

● How to calculate the power supply input energy:

Equation 9

$$E_{in} = \frac{P_{in}}{f}$$

Equation 10

$$P_{in} = \frac{P_o}{N}$$

Equation 11

$$E_{in} = \frac{P_o}{fN}$$

● How to calculate the peak bulk voltage:

Equation 12

$$V_{b_{pk}} = V_{dc_{off}} - V_d - \frac{R_{in}P_o}{NVdc_{off}}$$

Equation 13

$$V_{b_{min}} = \sqrt{\left(V_{dc_{off}} - V_d - \frac{R_{in}P_o}{NVdc_{off}}\right)^2 - \frac{P_o}{CfN}}$$

● How to calculate the bulk energy at low bulk voltage minus the load energy for HOLD-UP time T_{up}:

Equation 14

$$E_{bulk_{off}} = E_{bulk_{on}} - E_{load}$$

Equation 15

$$E_{bulk_{on}} = \frac{C \bullet V_{b_{min}}^2}{2}$$

Equation 16

$$E_{load} = \frac{P_o T_{up}}{N_o}$$

Equation 17

$$E_{bulk_{off}} = \frac{C \bullet V_{b_{min}}^2}{2} - \frac{P_o T_{up}}{N_o}$$

● How to calculate minimum DC bulk voltage:

Equation 18

$$V_{dc_{min}} = \sqrt{\frac{2E_{bulk_{off}}}{C}}$$

Equation 19

$$V_{dc_{min}} = \sqrt{V_{b_{min}}{}^2 - \frac{2P_o T_{up}}{CN_o}}$$

Equation 20

$$V_{dc_{min}} = \sqrt{\left(V_{dc_{off}} - V_d - \frac{R_{in}P_o}{NV_{dc_{off}}}\right)^2 - \frac{P_o}{CfN} - \frac{2P_o T_{up}}{CN_o}}$$

●   How to factor out P_o/C:

Equation 21

$$V_{dc_{min}} = \sqrt{\left(V_{dc_{off}} - V_d - \frac{R_{in}P_o}{NV_{dc_{off}}}\right)^2 - \left(\frac{P_o}{C}\right)\left(\frac{1}{fN} + \frac{2T_{up}}{N_o}\right)}$$

Equation 22

$$V_{dc_{off}} = V_{ac_{off}} \bullet \sqrt{2}$$

Equation 23

$$V_{dc_{min}} = \sqrt{\left(V_{ac_{off}} \bullet \sqrt{2} - V_d - \frac{R_{in}P_o}{NV_{ac_{off}} \bullet \sqrt{2}}\right)^2 - \frac{P_o}{C}\left(\frac{1}{fN} + \frac{2T_{up}}{N_o}\right)}$$

●   Solving for C in *Equation 23* :

Equation 24

$$C = \frac{P_o\left(\frac{1}{fN} + \frac{2T_{up}}{N_o}\right)}{\left(V_{ac_{off}} \bullet \sqrt{2} - V_d - \frac{R_{in}P_o}{NV_{ac_{off}} \bullet \sqrt{2}}\right)^2 - V_{dc_{min}}{}^2}$$
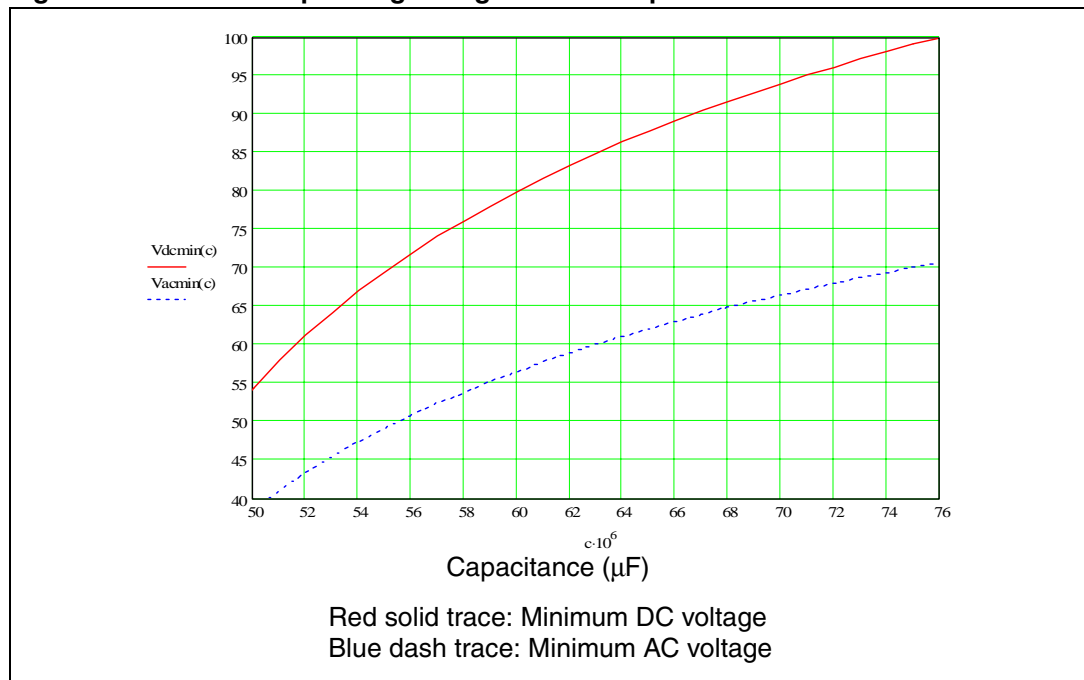
6 HOLD-UP graph: T_{up} = 10 ms

Equation 25

$$V_{dc_{min(c)}} = \sqrt{\left(V_{ac_{off}}\sqrt{2} - Vd - \frac{R_{in} \bullet P_o}{V_{ac_{off}} \bullet \sqrt{2} \bullet N}\right)^2 - \frac{P_o}{c} \bullet \left(\frac{1}{f \bullet N} + \frac{2 \bullet T_{up}}{N_o}\right)}$$

Equation 26

$$V_{ac_{min(c)}} = \frac{V_{dc_{min(c)}}}{\sqrt{2}}$$

Figure 1.   Minimum operating voltage vs. bulk capacitance

Red solid trace: Minimum DC voltage
Blue dash trace: Minimum AC voltage

6.1 HOLD-UP example

- $V_{ac_{off}}$ = 110 AC voltage at turn-off
- P_o = 24 Output power
- η = 0.84 Efficiency running
- N_o = 0.87 Efficiency at turn-off
- $C = 60 \bullet 10^{-6}$ Bulk capacitor
- f = 60 Line frequency
- $T_{up} = 10 \bullet 10^{-3}$ Desired HOLD-UP time
- V_d = 1.2 Voltage drop of the input diodes
- R_{in} = 5.5 Inrush resistor and EMI filter resistance in the AC line

Equation 27

$$V_{dc_{min}} = \sqrt{\left(V_{ac_{off}} \bullet \sqrt{2} - V_d - \frac{R_{in} \bullet P_o}{V_{ac_{off}} \bullet \sqrt{2} \bullet N}\right)^2 - \frac{P_o}{C} \bullet \frac{1}{f \bullet N} + \frac{2 \bullet T_{up}}{N_o}} \qquad V_{dc_{min}} = 79.9$$

$V_{dc_{min}} = 79.9$ The minimum DC input voltage that the power supply will run:

Equation 28

$$C = \frac{P_o \bullet \left(\frac{1}{f \bullet N} + \frac{2 \bullet T_{up}}{N_o}\right)}{\left[\left(V_{ac_{off}} \bullet \sqrt{2} - V_d - \frac{R_{in} \bullet P_o}{V_{ac_{off}} \bullet \sqrt{2} \bullet N}\right)^2 - V_{dc_{min}}\right]^2} \qquad C = 60 \bullet 10^{-6}$$

Figure 2.   P-Spice schematic
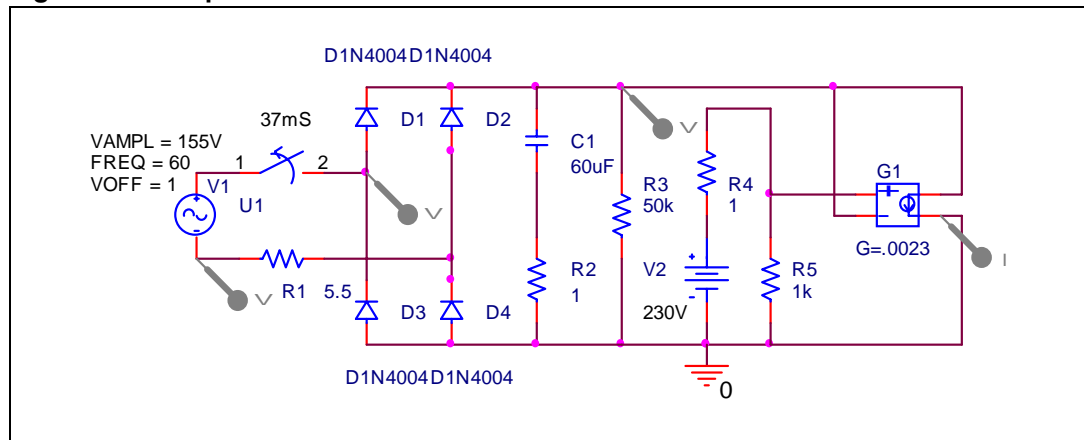
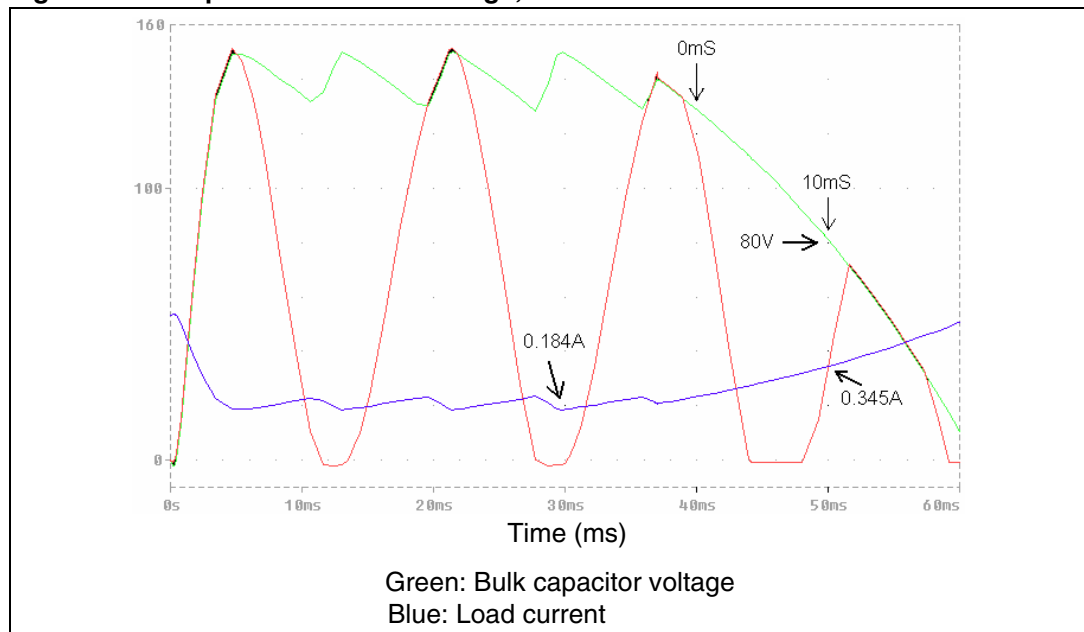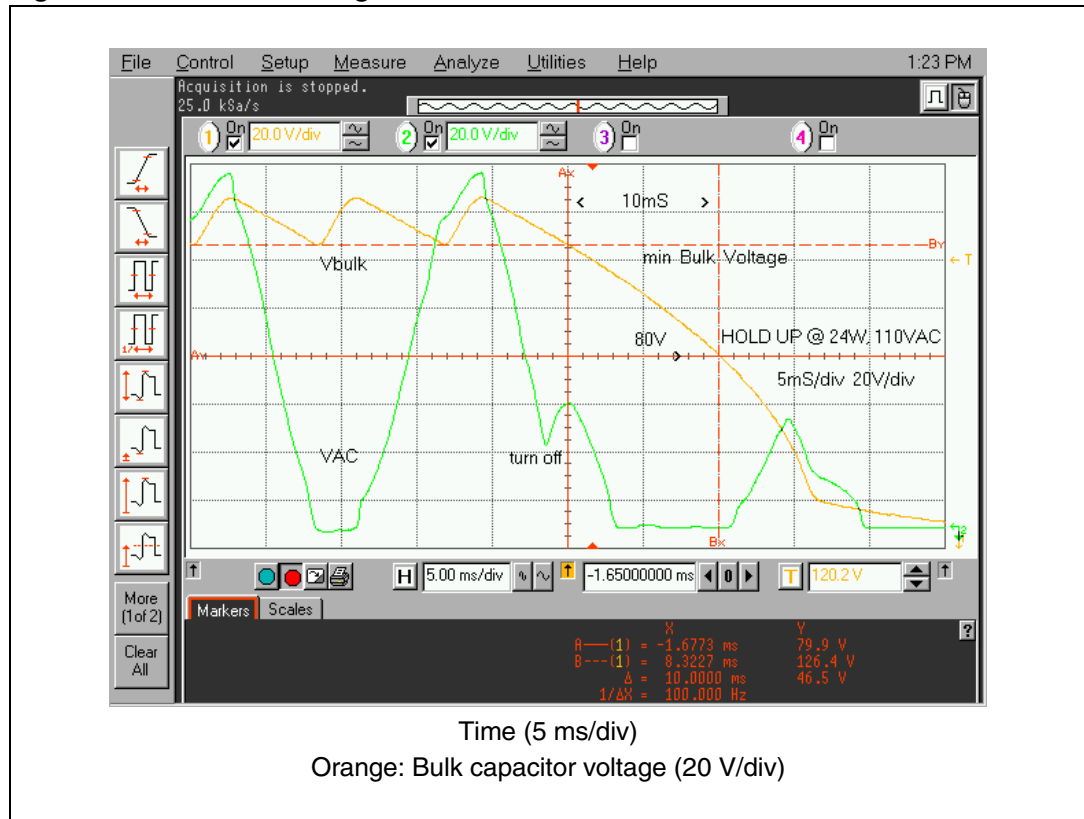**Figure 3.   P-Spice simulation - voltage, current vs. time**

Green: Bulk capacitor voltage
Blue: Load current

Figure 4.   VIPer53 power supply schematic

Figure 5.　　Measured voltage vs. time

Time (5 ms/div)
Orange: Bulk capacitor voltage (20 V/div)

7　　VIPer53DIP-E (see *Figure 4*)

The VIPer53DIP-E has a state-of-the-art, enhanced current mode PWM circuit combined with an optimized avalanche rugged high voltage MDMesh Power MOSFET in the same package. The VIPer53DIP-E used for this application has an $R_{ds(on)}$ of 1.0 Ω, a peak current of 1.7 A, a drain to source voltage rating of 620 V and is capable of 30 W for a wide voltage range input voltage in the discontinuous flyback mode. It also has an overload delay at TOVL controlled by an external capacitor.

The TOVL function is well suited for various length power line drop conditions which could cause damage or overheating to the power supply. An external capacitor, C6, is used to delay the overload protection to meet the designed HOLD-UP time specification and then protect the power supply while entering an endless restart sequence. The VIPer53DIP-E resumes normal switching immediately after the line voltage returns to the power supply designed input voltage.

8 Revision history

Table 2. **Revision history**

Date	Revision	Changes
08-Feb-2007	1	First issue

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