Up/Down Converter Linear Model with Feed Forward and Feedback Stability Analysis

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Abstract

After knowing most power electronics circuits, we can say that the operation that we expected are under ideal conditions. The goal of power conversion was achieved by proper circuit configuration and proper switching. Our electronics circuits are treated under ideal conditions and operate in a nominal way. The steady state in most power electronics circuit is periodic steady state. Usually the focus is in operation were the behavior is the same from cycle to cycle.

In this paper we will deal with disturbances that will cause the power electronics circuit to deviate from nominal. This includes unexpected changes in the input or load. Also we look at the transient due to start. This deviation from nominal is called dynamic behavior. If this dynamic behavior do not change the desired output significantly we do not do any corrective action. This is rarely the case, however.

We have to design the system in order not to deviate from the desired nominal conditions. We need a control system recover to desired specifications. The compensator must operate to restore nominal conditions. second, it must maintain the circuit and guide it to nominal conditions by advancing or delaying the switching time. In this paper we are going to analyze the dynamic behavior due to disturbances or fault and how to control and guide the system to normal.

The focus in this paper is dynamics and control and an appropriate model for the non linear circuit to apply this control. From our experience we conceder faults that the system might fall into and we consider treatment from these situations. In our treatment we consider more parameters and more elements to have more flexibility to control the system. The cost of falling in one of these faults might be too high so we have to think of a solution.

Keywords: Power Electronics, Converter, Control. Dynamic Behavior.

1. INTRODUCTION

First we have to select a good model. The model have to include the effect of the disturbance on the system and a controller that makes the regulating action. We have to specify nominal operation and in the case of disturbance we have to guide the system to this nominal.

In open loop control the controller is not given information about the system output. The open loop control use some measurements of input disturbance and feed forward the control signal to act to correct the output, feed forward alone usually is insufficient to give satisfactory results.

A better strategy is to measure how much the output departed from nominal. When the controller have this information, it will act rapidly and safely to restore the system to nominal. This is called closed loop feedback control. If the model update itself on the base of measurements, we call it adaptive.

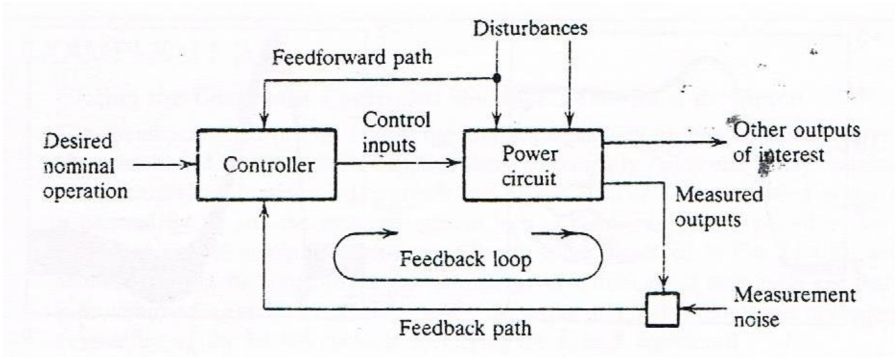

FIGURE 1: The Typical Control System Configuration.

A typical situation is figure 1. As you can see it is a feedback control loop. The measurement at the output is fed back to the controller to guide the system to nominal.

The input to the controller are disturbance and measured output and the desired value. Unmeasured disturbance and modeling error cause the controller to have undesired effects. The output given to the controller is corrupted by noise and we have also sensor noise. The noise and the modeling error and unmeasured disturbance all causes inaccuracies.

2. OPEN-LOOP CONTROL WITH FEED FORWARD FOR AN UP/DOWN CONVERTER

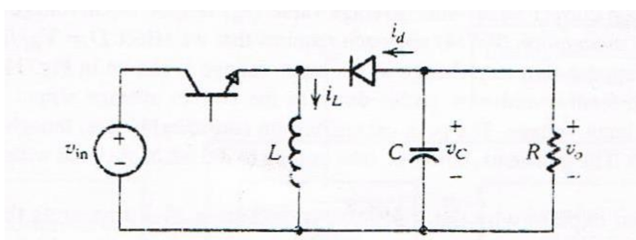

FIGURE 2: Circuit Schematic of the Power Stage of an Up/Down Converter.

Let us conceder the up/down dc/dc converter in figure 2. It operates at frequency 50khz R=2 Ohm C=220 micro F and L=.25 mH. We want to keep the output within 5% of the nominal value Vout=-9 v despite a change in the input from 12v to 8v. to simplify things let us assume that the transistor and diode are ideal switches.

For this dc/dc converter Vout = -Vin (D/D') were D is the duty cycle and D' =(1-D). For our specification D = .43 and the dc/dc converter operate in the continuous mode.

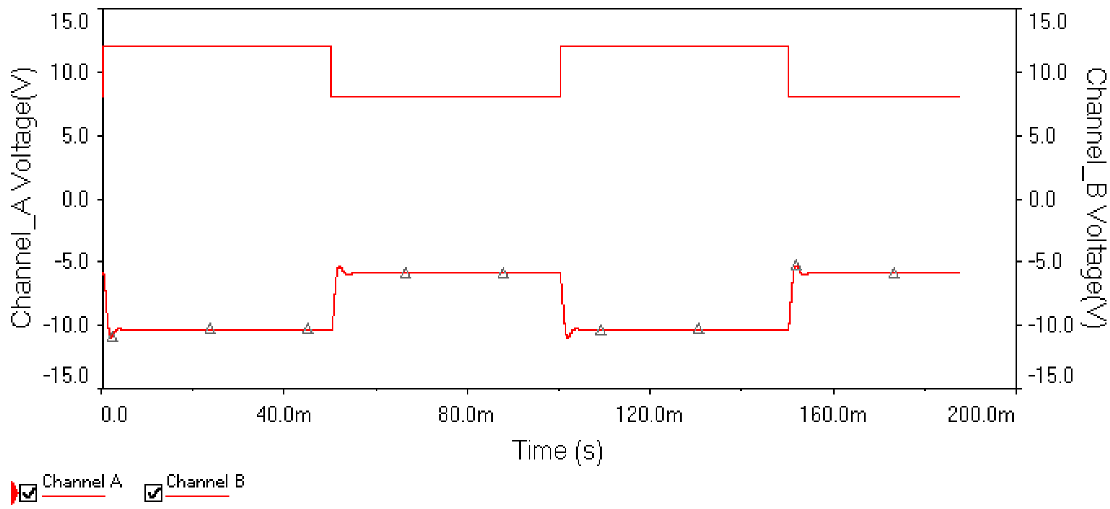

FIGURE 3: Response to the System as Vin Change from 12v to 8v.

As we can see in figure 3 as the input change from 12v to 8v the output change. The system give us the nominal voltage when the input is 12v. As the input change to 8v in a step the output will go on oscillatory transients and settles down to incorrect value. We will explain the transient by a model that we will develop.

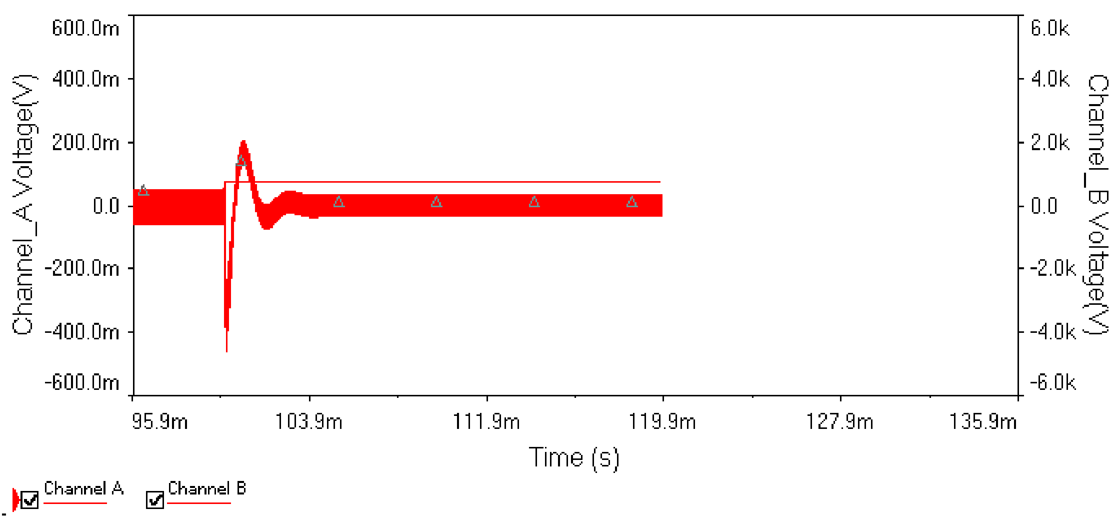

FIGURE 4: We have Feed Forward Using PWM.

A solution to the change in the input voltage is to use feed forward. If D is made to vary so that –VinD/D' is constant as Vin changes, this can be a solution to make Vout constant. This pulse width modulation need to chose D=Vref/(Vref-Vin).

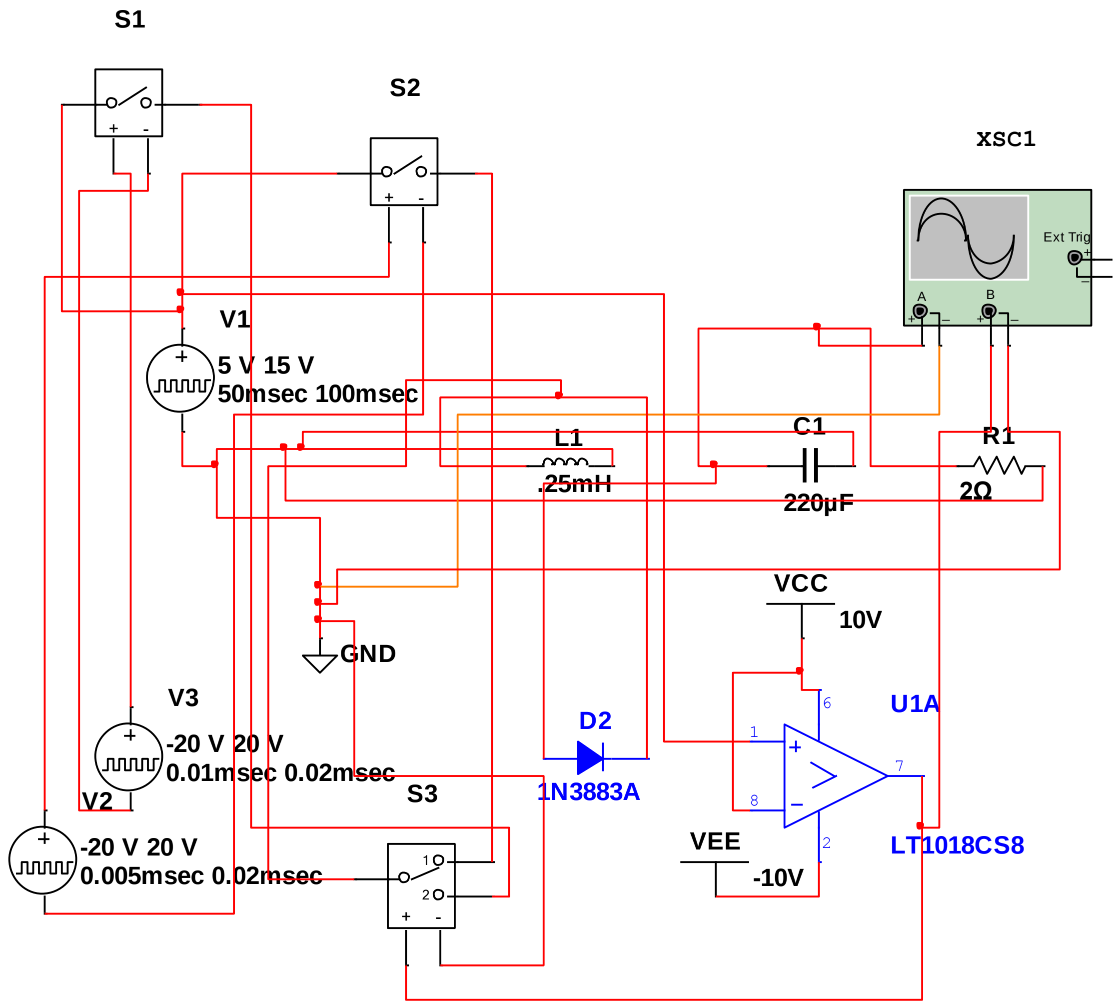

FIGURE 5: We Have Feed Forward Using PWM.

The resulting response is as in figure 4. The system now settles to the reference voltage even if the input vary. As we can see we have a transient that take a long time to die out as without feed forward.

3. A LINEAR MODEL FOR THE UP/DOWN CONVERTER TO EXPLAIN THE TRANSIENT

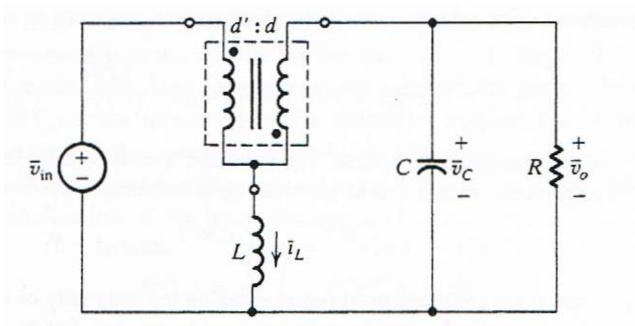

FIGURE 5: A Linear Model for Up/Down Converter To Explain the Transient .

The linear model that can explain the transient is as shown in figure 5. The linear transformer is replaced for the two switches the transistor and diode. We also replace instantaneous quantity by the average.

This averaged circuit can be used as a basis to generate other types of analytical model such as state space model. The circuit can be used in simulation packages. Note that this circuit depend nonlinearly on the control variable d(t). The process of linearization deal with this nonlinearity.

When d is constant the analysis is straightforward. By that we mean the circuit can be used to read voltages and currents when we have v in and D. in the steady state the inductor voltage and the capacitor current is zero. So we can say that

$$I_L = \langle i_L \rangle = -\frac{V_o}{RD'} \quad \text{and} \quad V_o = \langle v_o \rangle = -V_{\text{in}}\frac{D}{D'}$$

This averaged circuit give us a basis to understand the result in figure 3. Were we examine the open loop response to the step in the input Vin. D is constant. The transfer function is given as

$$\frac{\overline{v}_o(s)}{\overline{v}_{\text{in}}(s)} = \frac{-D'D/LC}{s^2 + (1/RC)s + (D'^2/LC)}$$

The switching period is small if we compare with the settling time so we can use this approximation.

The response is determined by the poles of the under damped system

$$\lambda_1 = \lambda_2^* = -\frac{1}{2RC} + j\omega_D \quad \text{and} \quad \omega_D = \sqrt{\frac{D'^2}{LC} - \frac{1}{4R^2C^2}}$$

These poles give us the response

$$c_1 e^{\lambda_1 t} + c_1^* e^{\lambda_1^* t} = ce^{-t/(2RC)} \sin(\omega_D t + \theta)$$

A graph of response is figure 3

A detailed calculation biased on the transfer function account very well not only qualitatively but also quantitatively for the average behavior of the open loop step response. The time constant 2RC is 880 micro s or 44 switching cycle. And the period 2 pi/w is 2924 micro s or 145 cycle. A similar calculation can be carried out with feed forward. In this case D change as a step as well by a value determined by V in. next we will develop a model for forward feed back that includes PWM by D to control the system.

4. THE UP/DOWN CONVERTER LINEAR MODEL INCLUDING FEED FORWARD AS PWM MODULATED BY THE CHANGING INPUT TO CONTROL THE SYSTEM

The linearized model is obtained of figure 5 by replacing all voltage sources and current sources by the perturbation from nominal and replacing the averaged conical cell by its linearized version. All other elements are linear so they stay the same. The result is figure 6 with v in as the change is input voltage from its nominal dc value

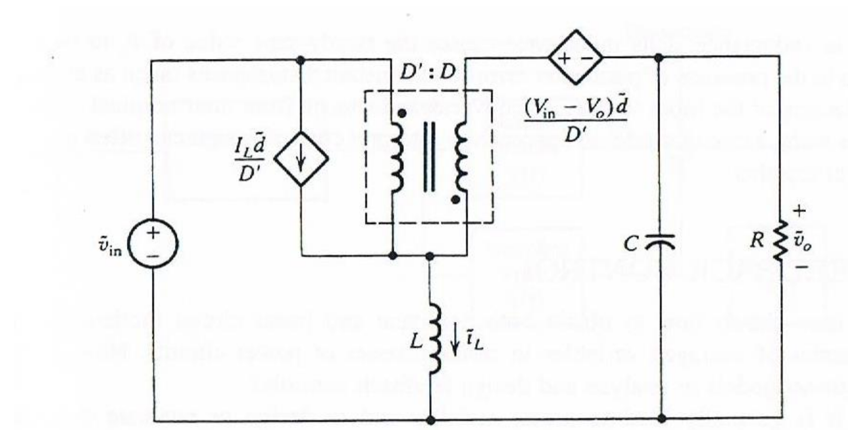

FIGURE 6: The Linearized Up/Down Converter Model Including Feed Forward by D For Simulation Using Circuit Software.

This model give us a linear model which result on constant output Figure 4. We can solve for the transfer function.

$$\frac{\tilde{v}_o(s)}{\tilde{d}(s)} = \left(\frac{I_L}{C}\right)\frac{s - (V_{in}/LI_L)}{s^2 + (1/RC)s + (D'^2/LC)}$$

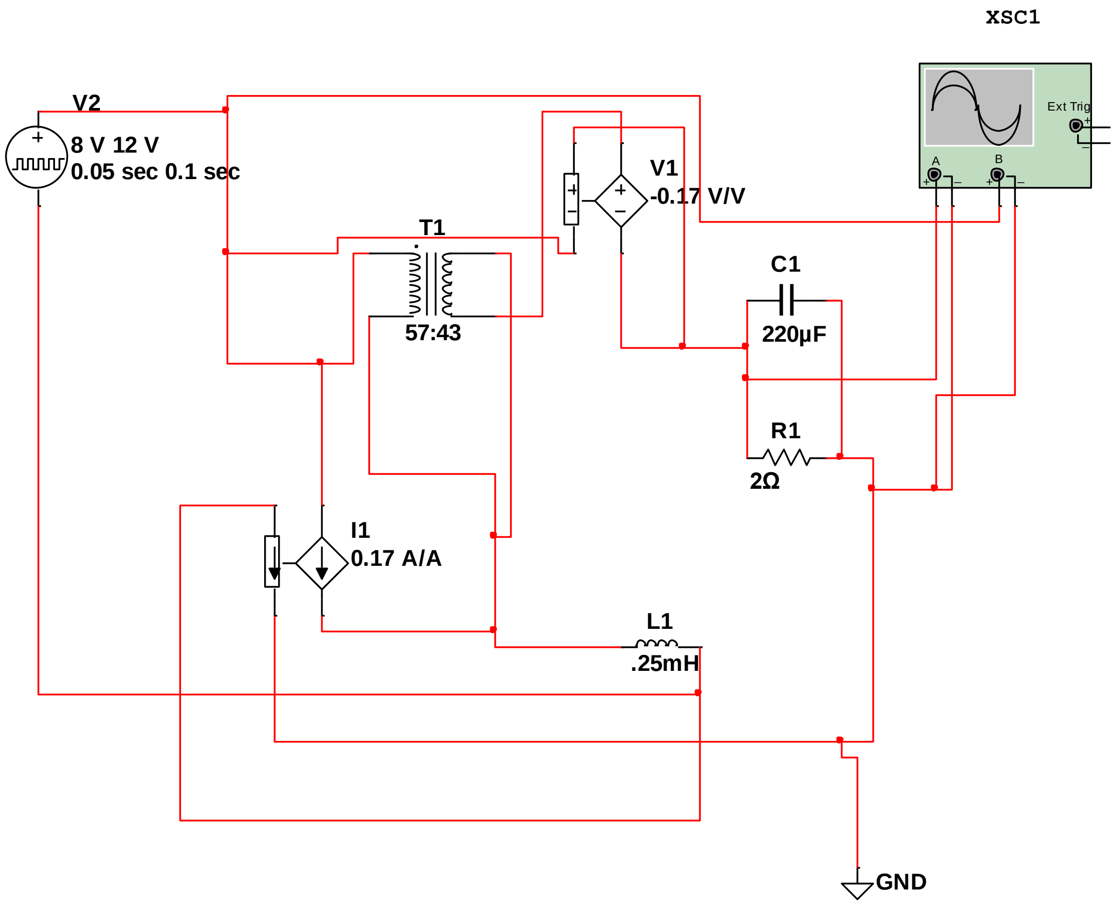

FIGURE 7: Simulation of The Circuit In Figure 6.

This is a good example of feed forward and also a good starting point for proportional feed back which we will develop next.

5. PROPORTIONAL FEED BACK CONTROL OF AN UP/DOWN CONVERTER

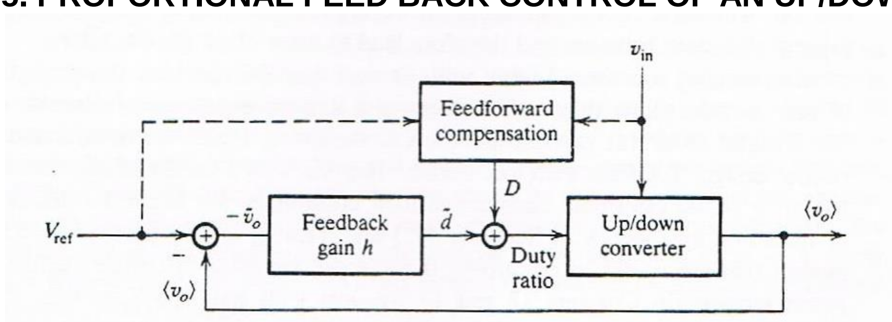

FIGURE 7: Proportional Feed Back Control of Up/Down Converter.

The desire for better performance than obtained with open loop and feed forward of the up/down converter lead us to conceder feed back control solution. We have to measure the output and see how much it deviate from the nominal V out = -9 volt. And use the error to adjust the duty cycle.

We look at Vout. If V out-V ref is negative we should decrease the duty ratio. Similarly if the error is positive we should increase the duty ratio. This is the natural PWM control law suggested by steady state characteristics.

The proportional feedback control system in figure 7 is one implementation of this law. The change in duty ratio is proportional to the deviation in V out. H is the feedback gain. The block diagram show that feed forward examined earlier is included.

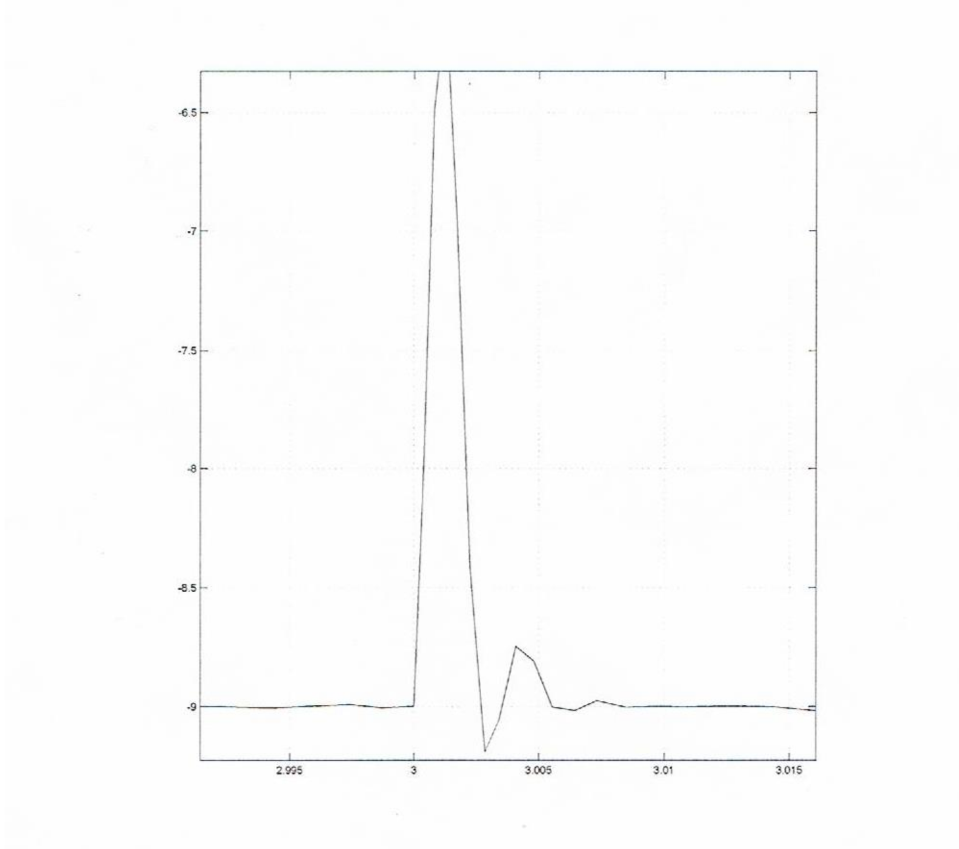

FIGURE 8: Show the response to the same step for gain -.03 with feed back and feed forward in place. The response become oscillatory and goes unstable for very negative h.

6. STABILITY OF UP/DOWN CONVERTER UNDER PROPORTIONAL FEEDBACK

We want to explain this result. The feed forward does not effect stability so we ignore it in this example. The diagram will look like this

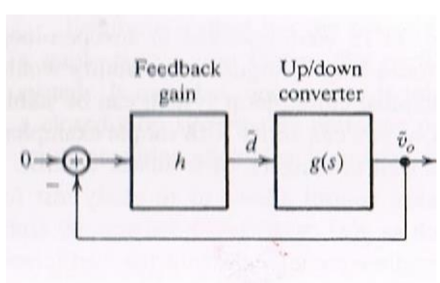

FIGURE 9: The Block Diagram of the Control System.

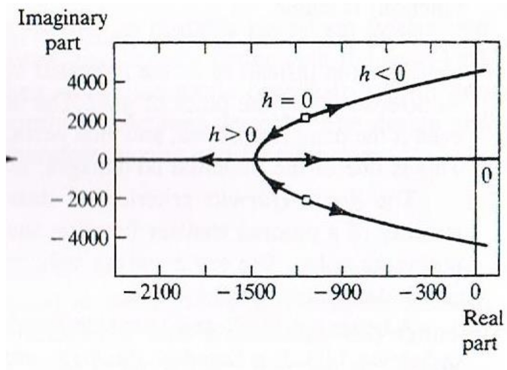

FIGURE 10: The Poles As The Gain Change.

The transfer function g(s) is the same as given. The sensitivity function in this case is

$$\mu(s) = \frac{s^2 + (1/RC)s + (D'^2/LC)}{\left[s^2 + (1/RC)s + (D'^2/LC)\right] + h(I_L/C)\left[s - (V_{in}/LI_L)\right]}$$

To satisfy the stability condition h has to be

$$-\frac{1}{I_L R} < h < \frac{D'^2}{V_{in}}$$

The roots are also the natural frequencies of the system. Figure 10 shows the roots as h changes. As decreases and become more negative the roots are closer to the imaginary part and the graph in the time domain correlate very will with the roots. For small value of h as it increases the roots move away from the imaginary axis giving a more damped response. This also correlate very well with the time domain response.

7. COMPARATIVE EVALUATION

Vorperian did some work on this (Simplified analysis of PWM converters using a model of PWM switch) in 1990. Lee did some work (Equivalent circuit models for switched power converter) in 1989. Doyle and his book (Feedback control theory) talk about this in 1991.

8. CONCLUSION

Simulation and modeling is important. For example this up down converter is non linear. Can we make a linear system that will give us the same output?

Let us say that system one is a square wave at the switching frequency which is the input to an RC circuit. System two is an RLC circuit with a step response as the transient of the up/down converter. The sum of the output of system one and two is the same as the output of the converter and system one and two are linear. This is a linear system which have the same output as the non linear.

For more critical discussion let us say the input to the RC circuit have D duty cycle. The sum of system one and two will be exactly the same as the non linear converter.

I think the correlation between the two systems will be a potential for future research . As you can see this system is linear and the up/down converter is not. The output of the two are the same signal. How can we correlate between the two?

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