Design and Simulation of DC-DC converters using open source tools

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Lecture – 21

Close Loop Operation of Converters

Till now we have been studying converters in open loops, we studied the buck boost, buck converter, the boost converter, the buck boost converter, isolated converters like the forward, fly back, the half bridge, full bridge, push pull and such converters where the open loop operation was described. But the ultimate objective is to see that the output voltage is well regulated, in the sense that if there is a variation in the input voltage, variation of the temperature or even variation in the load the output voltage v knot has to be regulated to a more on this constant value. This would be the objective that we would like to put before ourselves for any kind of a power supply.

Now, to do that we need to have controller and feedback the output voltage and the controller should take a decision based on the error and accordingly change the duty cycle, which is actually the control input for most of the controllers, most of the d c d c converters. So, in order to do this regulation; v knot is spread back and compared with the reference and passed on to a controller which could be a proportional or proportional integral or a p i d proportional integral derivative type of controller and the output of which goes to a p w a modulator, pulse width modulator and eventually to the gate drive and the controllable switch which we have used till now in almost all of a open loop d c d c converters, so this would be the plan while closing the loop.

So in this section of the video lecture, I will try to focus on close looping the converters, so I will take examples like the buck converter, the boost converter and try to close the loop in a negative feedback way and then see how the controller works and then probably we can look at some simulation examples so that you get some practice on how to go about doing the close loop operation of d c d c converters and same concept, similar concept can be applied even to the isolated converters and other d c d c open loop converters which you may encounter in future.

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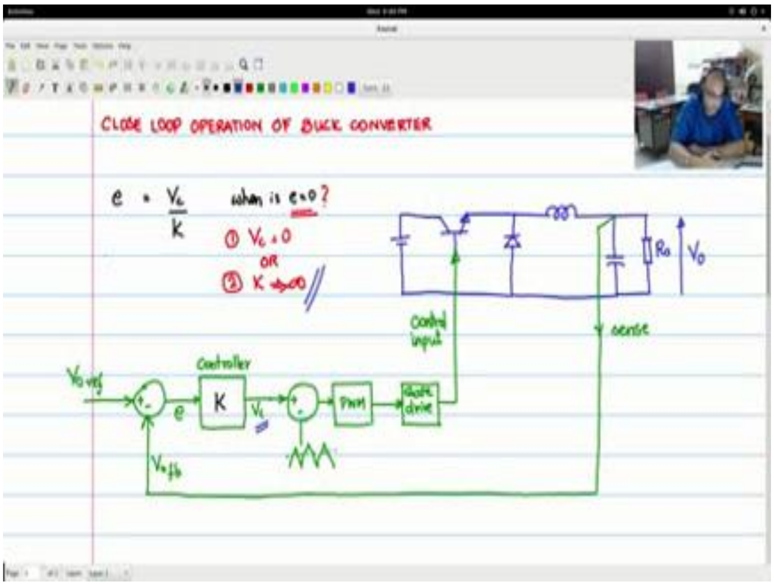

Let us discuss the close loop operation of the buck converter; the process is similar even if it is for any other type of converter. So, let us draw the buck converter circuit burst, so we have an input and let us say it is coming from the battery for now, it could come from the output the rectifier to and let us say I have a switch; now this switch which I am showing as a b j t can as well be an i g b t or even a MOSFET and I have this diode followed by the output filter circuit, which is the inductor and the capacitor combination.

You are now very well familiar with the buck converter circuit, now this is the buck converter circuit, this is r knot and the voltage across that is v knot and let us say that we are giving the gate drive to the base of the transistor and we will sense, we need to sense the output voltage. So, this is what you call the sense variable and this is the control variable or even control input, to the control input here is variation in d; variation in the duty cycle, so let us sense the output pass it through appropriate circuitry.

So, let us say we sensed appropriately amplified or attenuated and bring it to a comparator at difference amplifier. So, here let us set the v knot reference this is what is desired v knot references, what is desired and we need to compare the feedback v knot feedback value with the v knot reference value and the difference gives the error e and the error is (Refer Time: 07:00) to the controller. Now this is the controller which can be p p i or a p i d and in many cases it can be a proportional integral controller and the output of this p i controller is compared with that triangle.

Now, this is the triangle carrier which actually determines and defines the switching frequency of the convertor and this v c is the compare signal, let us say this is v c control voltage, is the compare signal for the triangle and which will produce the modulation; p w modulation. So, this actually is your p w m circuitry, which will go through a gate drive circuitry, gate or a base drive and given to the gate or base of the power semiconductor switch.

So in a block schematic manner, this is how the closed loop system looks like so that blue portion of the system here; on this page all this blue portion is the open loop system and to that in the blue portion, we saw that you just gave control v c as a constant voltage, compare it with the ram and that was the p w module compare and the p w m generation gate drive and giving it as a switch on and off condition for the power semiconductor switch and all the rest to the blue portion per the power circuit portion.

So, v c constant and all these portion along with the power components form the open loop system and now what we have added is a sense circuitry which should measure the output voltage that needs to be controlled appropriately amplified or attenuated and then filtered and then given to a comparator, which compares the feedback signal with a reference signal, this is actually the set point; this is our desired value what the v knot should eventually be, it is compared with that and an error signal is generated so the difference between the set point reference value and the feedback value.

The error is given to the controller and the controller will generate a output, control output which is v c which gets compared with triangular carrier, generates the p w m and switches the transistor on and off in accordance with the error in such a way that the error here is made 0, once the error here goes 0 then v knot feedback and v knot reference are same and then we can say that the output is regulated constant here respective of changes in v, changes in temperature or even changes in the load.

So, this is our objective and this is how the control system would look like, later on probably what you could do is; you could replace this blue portion of the power circuit by different d c d c converters, you could connect a boost converter, you could replace this blue portion of the power circuit by different d c d c converters, you could connect boost converter, you could replace this with a buck boost converter, but appropriately give the control input to the specific power semiconductor device and it is specific position so that it will do the job of switching on and off the particular converter and act as a single pole double throw switch and likewise you could also give it to the isolated converters like the forward fly back converters and the other types of the converters.

Now, let us just examine this controller aspect a bit more before we go to the simulation. Now consider the controller and let us focus on these 3 variables e v c and the gain of the controller, I have indicated p i; a proportional integral controller, but let me erase this and replace it by a general gain k. So, let me put the value k here, so now this is the gain of the controller and let us try to look at the play of these 3 variables e k and v c, e is the error input to the controller, v c is the control output voltage. So, they are related in this following manner; e error is equal to v c by k, now straight forward relationship, now when is e equal to 0, now this is a important question that we need to answer. Let us say when is e equal to zero, now looking at the equation e k e is 0 either first case, v c is equal to 0 or second case k, tells the infinity.

Now, let us take the first case; if v c is equal to 0 what it means that I am grounding it at this point, this point is grounded. Now the moment you ground that point, it means that there is no meaning in putting all these controller, like in the open loop operation where we had given a fixed value of voltage to v c, this becomes a open loop operation, the whole circuit is in open loop then what is the meaning of during close loop. So, close loop operations cease to exist so we cannot make v c as 0. So, let us go for the other option; k tending to infinity, if k is infinity then whatever may be the value of v c, v c divided by infinity will give me 0 error. So, in the case of p i controller, the p i controller has a gain k; which is infinite as the system attends towards d c situation or a stabilized situation.

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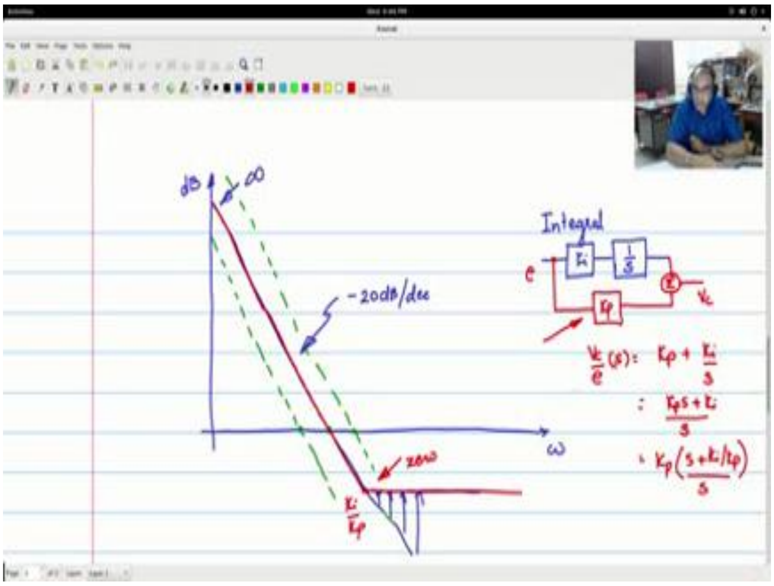

Let me take for example the first page, in the case of a i, this is omega verses omega and let us say this is d b, gain in d b; gain of the i in d b. So, let us first take i, what is i? i is a integral, i is a integral and let us say nothing, but 1 by s, so 1 by s is nothing but a bode plot which goes at minus 20 d b per d k; minus 20 d b per d k and what is the value at omega is equal to 0, at omega is equal to 0; here the gain is infinite. So if you to be integral, the gain is infinite at d c are at stable region, which means that the error is 0. So, an integrator will provide you with the means to achieve 0 steady state error because of an infinite gain whatever may the value of v c; error is equal to 0 because v c by infinity will be 0. So, if you put as scalar, scaling value k i then what basically happens is depending upon the k i is greater than 1 or less than 1 gain or attenuation, you will be choosing different parallels which will change the band width.

So, if you have a measure of control on this speed of response, so k i is one aspect. Then let us say instead of allowing this to go in the fashion; like this at somewhere this point, I tried to flatten it out; then in the high frequency of origins of the omega. I have a bit more gain and this can improve my dynamics, which means if you have to flatten out the curve, so my integral action is here, the integrator and at this point you want to wave shape it, you want to shape the gain curve like this instead of allowing it to go at minus 20 d b per d k, you make it 0 d b per d k, what does it mean; you are putting a 0 here, you introduce a 0 at this point. So, let us say that I introduce a proportional part k p and you add it to the integral part.

Now another this is e and this is v c, so what is the transfer function between v c and e, now this is k p plus k i by s, k p plus k i by s; now this is equal to k p s plus k i, further simplifying I will say k p s plus k i by k p by s. So, just by introducing a proportional gain you have now introduced as 0, at s is equal to minus k i by k b. So, this at k i by k p ratio corresponding s omega, you have a 0 and that has flatten down this curve and then you have got additional high frequency gain advantage, which will improve the transient response a better; bit better. So, this is the structure of the p i controller when viewed from the frequency domain and you see that, the p i controller has potential to have infinite value at d c are infinite steady state gain and because of that infinite study state gain, the p i controller is capable of giving 0 steady state error.

You could add a d much higher, to improve the fraction response, but most of the time it is not needed. So, you do not need to have a p i d controller, most of the cases p i controller surfaces when you added d be careful because you are increasing the gain and you are introducing a derivative component in the highly noisy high frequency zone and it can amplify noise. So, you have to be very very careful by introducing while introducing d or the derivative, so this is the concept of the p i.

So, going back into the previous page, I will now erase this generic k now and say that I would like to put a p i here because p i will give me a value of k is equal to infinity gain of infinite value at d c, so therefore the steady state value of the error will be equal to 0. So, therefore, it is a good practice to start off with a p i topology for most of the controllers and then take it from there and tune it and take it from there.