Advance Power Electronics and Control
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Lecture - 17
PWM Rectifiers III and Power Factor Improvement Techniques

Welcome to our courses on Advanced Power Electronics and Control. Today, we shall with our PWM rectifier and thereafter we shall see some technique on the improvement of the power factor. So we were discussing about the boost control.

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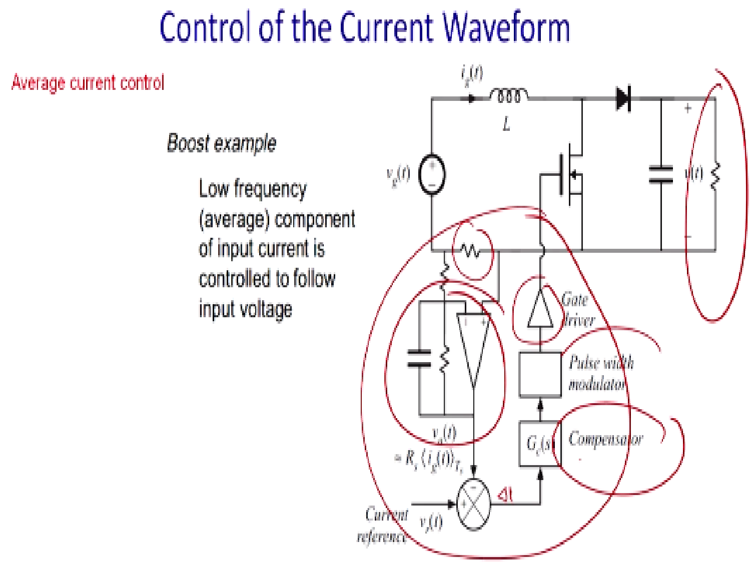

Now let us have to see that there is a different kind of control technique to operate the boost voltage. Essentially, you know main function is that to maintain the output voltage most of the cases of the boost one. So there is also a loop basically to maintain the voltage that is called the outer voltage loop we are not little bothered about it. So let us consider that there is a inner loop that will basically maintain that will basically deal with the current that is called inner control current loop.

What happens here actually there will be a current sensing resistor or you can do it with a hall effect sensor at present case and this is essential a PI controller. So is a practical PI controller integration and parallel path and you have a current reference that will be actually compared then this value of this actually error del I has been fed to the compensator. Generally, it is nothing but a lead-lag compensator depending on your faster response and all those things.

We have to have a gain margin phase margin of actually the system in a desired level. So this compensator essentially will do that. We will give you a desired gain margin and phase margin. Therefore, there is a pulse width modulator. The pulse width modulator basically generate the gate pulses and ultimately you require an isolations because you know pulse width modulations is a very low frequency and sinking out the current for the gate driver is not allowed for this numerical buffer to run high impedance mode.

This is one of the way to basically operate your boost converter that is called actually average current mode. You can have another mode called the peak current mode there actually you instead of you allow the current to boost up in a peak current mode and there also its own advantage each has its own advantage. Essentially if you go over the stability analysis stability analysis will be quite easy because you have a compensator, compensator ensure that actually does not go out system go out of the stability.

So see that how this concept can be incorporated in a actually PWM rectifier.

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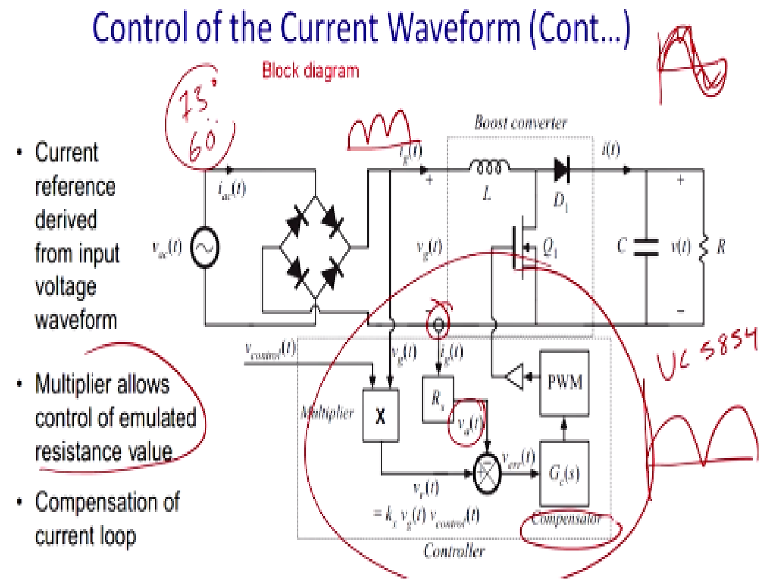

So essentially you know you have a repelled DC here in your output. So ultimately you will have a vt control and you got a multiplier. So you generally what happen instead of this you generate a sinusoidal wave. Basically it shift back this waveform in this part. Thereafter what happens most of the cases you will sense this current and you will sense this current and ultimately you will convert into a voltage by multiplying with the effective value of the resistor.

But here in this case it will be op-amp will give you the gain and ultimately you get a Va. Please note that actually you want actually this waveform and you want that current to also follow this waveform and thus in input side current will be something like that we will be contaminated with this envelope. So thereafter generally you have one block generally you have a hysteresis block generally that will generate the hysteresis band.

And there after you got a compensator that is essentially a lead-lag compensator that will ensure the stability of the circuit there at PWM again pulse is generated. I ask you to actually students to refer back to our practical power quality improvement boost type converter and generally this whole system comes under a single package of UC 5854 or 555 or so on. So what is a basic features of this PWM technique? Current reference is received from the input voltages waveform.

Multiplier allows control to emulate as a resistive load. So actually it will make it voltage and current almost is in a same phase and compensation of the current loop is employed by this basically a lead-lag-compensator to have a first time response actually low overshoot all those actually (()) (05:50). Generally, gain margin we required to keep around 75 to 60 degree.

So phase margin also actually we require to have a stability point of view we required to have something. So these all those tuning has to be done by this compensator.

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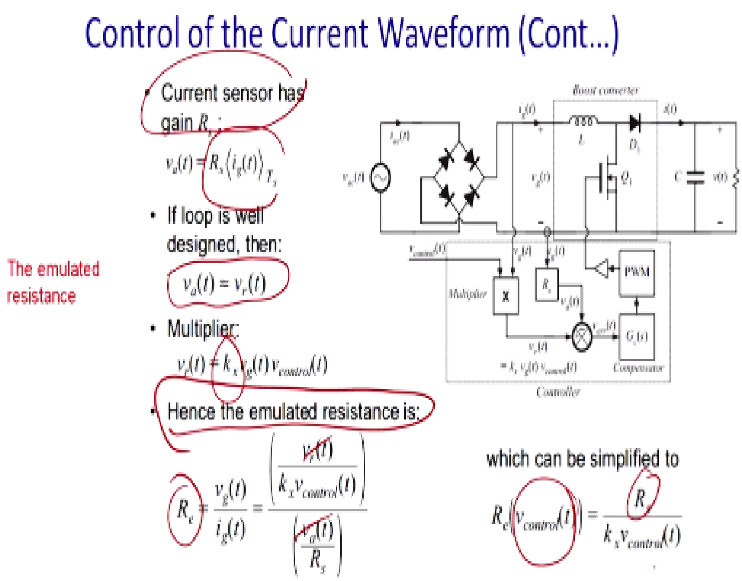

Now actually we shall see that how does it operate practically. The current sensor has a gain

Rs. So basically it has been multiplied we have a scaling because most of them nowadays we use LEM hall effect current sensor resistors. So that is actually va t Rs actually into multiplied by this actually this ig. Then loop is designed such that va is almost=vr and multiplier will ensure that vr= k* vg x.

So kx is basically a multiplier and that gives you basically v= vr kind of relationship. Hence it emulates the characteristics of the resistance. So you can see that effective resistance of the circuit Re=vg/i gt= vr kx control x/va/Rs. So ultimately you know you can make this is your effective resistance comes into the picture and you know this can be simplified. So this term and since if you say that va=vr so this term and this term will cancel ultimately you can write that Re that will be basically the function of the control voltage.

So that will be basically Rs/kx*v control*t. So Rs is again mostly it is fixed and so by controlling basically the control you will get a sinusoidal pattern into the input of this rectifier.

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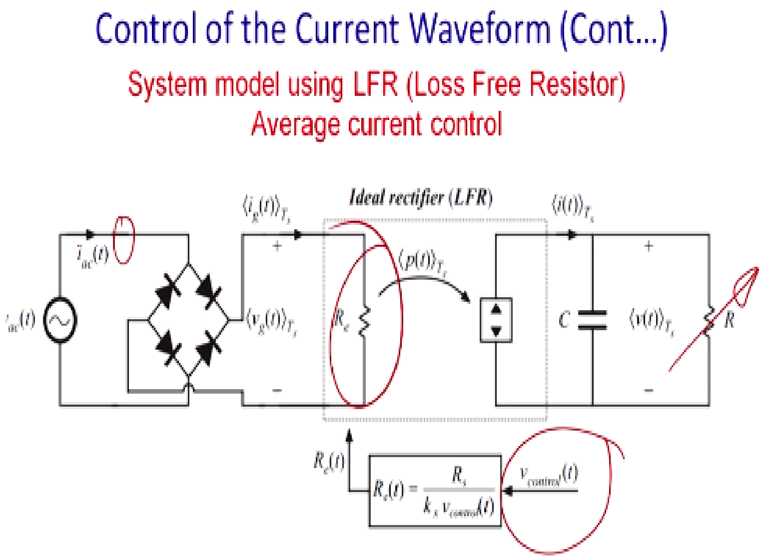

So see that actually if you have a transformer kind of model actually input and output so you have a effective Re and power will be transferred to the system. So Re will be basically Rs/kx vx control where you apply the control in such a way that it always sees sinusoidal current in the input of this rectifier irrespective of the load as well as the change of the source disturbance sometime.

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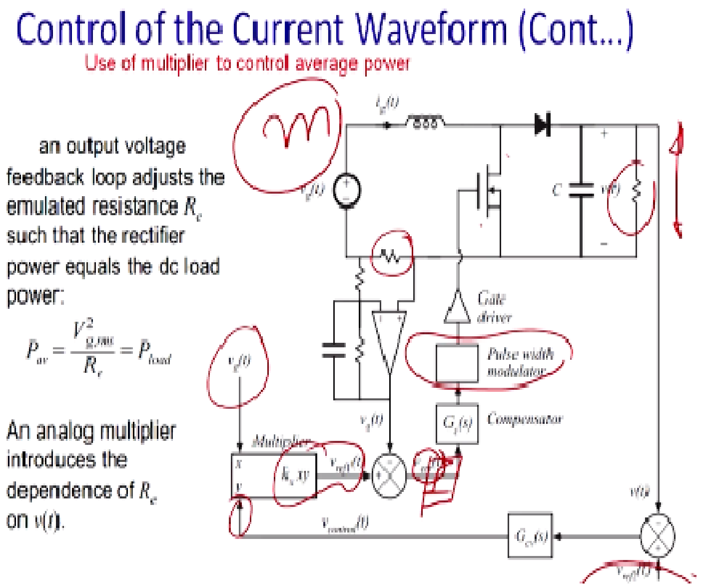

So current control waveform so this is something we required to like to take an example. As I told you know actually task of this converter is essentially to maintain the voltage here constant. So this is when I was telling few slides ago that there is a outer current loop also. So you have a voltage and it has been scaled down. By scaling down, you got a voltage reference. The outer has been multiplied by a scaling factor or it has been filtered out by a filter to actually suppress the high frequency noises or the ripple that will be there.

And ultimately this voltage will be fed to this actually y and same way this actually the rippled DC that is basically vg dt at this point. Please mind it basically this rectifier does not have a capacitor in the output thus we have a rippled DC. So that will be multiplied and you get some reference voltage that will be actually compared with the reference current multiplied by some constant.

So ultimately the current flowing through this part is there is input current to this boost converter so it will be convert and ultimately these comparison will gives you the error. Generally, error percent block fitted by a saturator so that actually you control over the duty cycle because you know the control point of view there is a limitation on the duty cycle. So generally we cannot go beyond 0.66 theoretically.

So this problem is there for the boost converter. So for this reason actually we have a limiter followed by a compensator that will basically give you the shaping of the gain margin and phase margin that will make the system prompt and you do not allow go to out of the control loop and all those issues will be actually addressed here by the lead-lad-compensator. So thereafter actually we have a pulse width modulator.

Pulse width modulator essentially generate the pulse and thereafter you got a high impedance state that will actually drive the MOSFET or IGBT depending on your power rating. If the power rating is low then generally this is the solution within a 500 watt or something this solution comes out with a MOSFETs and if the power rating is higher than we required to have a IGBT solution.

And if you have a huge power rating around more than 10 kilowatt then we may require to operate actually this boost converter in parallel and there are many topology like interleaved boost converter and all those things. So these can be incorporated according to the rating of the system.

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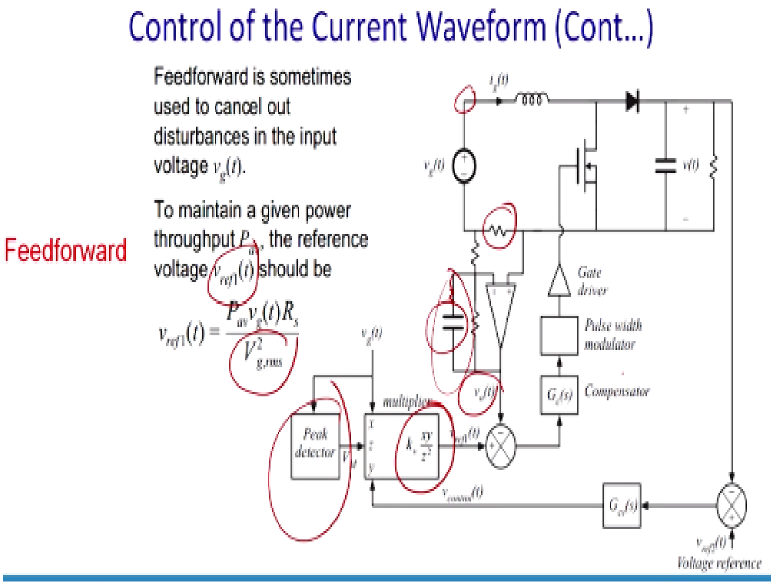

So let us understand how does it work? The Feedforward is sometimes is used to cancel out the disturbance of the input voltages. To maintain a given power throughput P average the reference voltage V ref 1 should be you know P average*v*Rs/ V square g rms. Now what happens this is that is point voltage is actually V square g. So you have a peak detector and you got V M and you got a multiplier.

So ultimately this output and this ripple voltage will be multiplied and will detect the peak. So accordingly you can adjust that whether there is a sag or swell something like that and accordingly you actually you get a value of basically kv xy/z square that essentially will set to the reference current. So ultimately it will be compared with a Va so this will be a current sensing resistor or hall effect sensor whatever may be.

And then this is actually PI controller this part basically integrate and this power is proportional and generally it required to put a small resistance in theoretically to have a bandwidth of the system. Bandwidth of the system will be related to the switching frequency of this actually the MOSFET or the IGBT driver. So generally in practical cases most of the cases if you use IGBT then frequency is restricted in around 5 kilohertz.

Then actually you can take this Rc bandwidth as basically 1/10 kilohertz that is actually 10 microsecond. So you can do in that way and calculate actual values of Rc and this gives you the gain so how much scaling you require. This actually some of the effect and thereafter you got a comparison from there you got a compensator. From the compensator we will basically gives you the stability and the promptness same way as I told you there is a PWM and it will work. So this is the overall control circuit of the boost type PWM rectifier.

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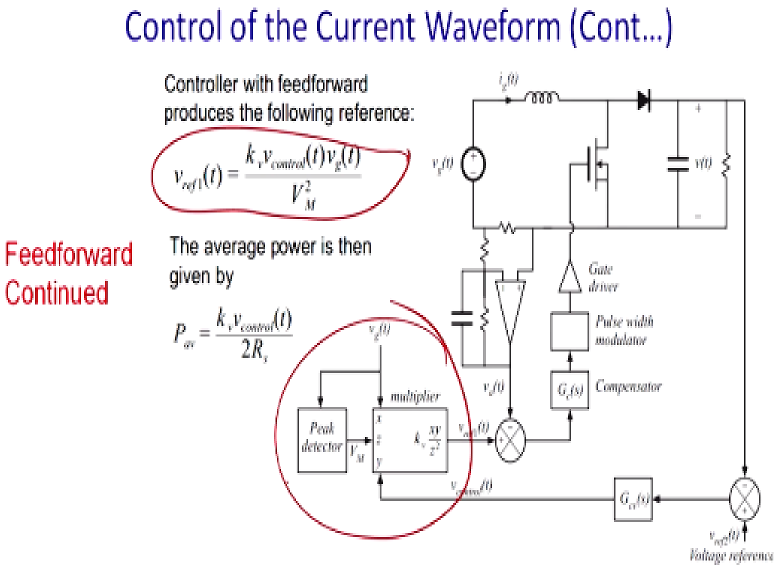

So there is a Feedforward control please understand that. Generally, feedback control gives a stability, but Feedforward control the promptness fastest in action. So Feedforward control has been produced by this reference. V ref1= kv control * vg t/ VM square so this is actually the Feedforward control block and the average power is then given by kv* v control/2*Rs where Rs is the effective value of the scaling resistor.

So in this way this is actually used for control. Now we can go for the small signal analysis for analyze the stability of this boost control converter PWM boost control converter.

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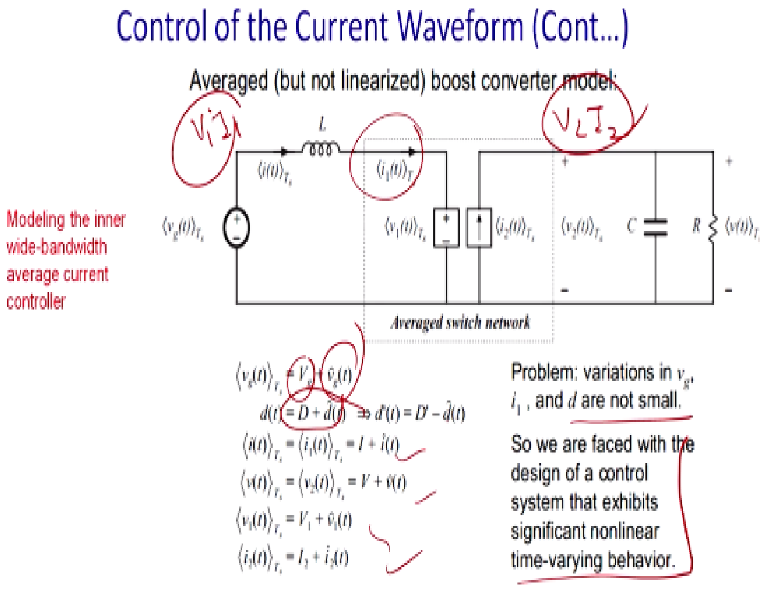

Now it is a average model so any phenomena< 10% of the switching frequency can be captured here and this is called small signal model. So what is a essential part of the small signal model we give a perturbation in an around basically since the system is nonlinear you have a switching you have a on and offset. So we did give a perturbations very close to the operating point.

Then we see that what kind of actually how this system will behave and this is called average modeling. So by average modeling we can capture the phenomena since stability which is actually one-tenth of the switch frequency. So we give a perturbations vg with vg delta similarly we have a perturbation vg dt delta and all given a perturbation all the parameter that is I Ts v Ts v1.

Please note that what are the this is basically the input current i 1 Ts. This is basically the voltage across the switches v1 Ts similarly the current in the model secondary basically v1, v2 it is something like transformer why because you know if you assume that switching losses and other losses are zero input voltage* input current should be= v2*I 2. So it is something like a step of transformer because energy conversion holds.

So for this reason we will have this values. Now problem of this actually the present is the variation of the vg because input voltage can vary because of the sag and swell of an I variation in vg i1 and D are not small. So you can have huge variation of this. So we are faced to design a control system that exist significant nonlinear time-varying behavior. So this is something quite trivial you know actually lot may change sag may occur.

So that basically not restricted that these assumptions so that systems becomes little complex.

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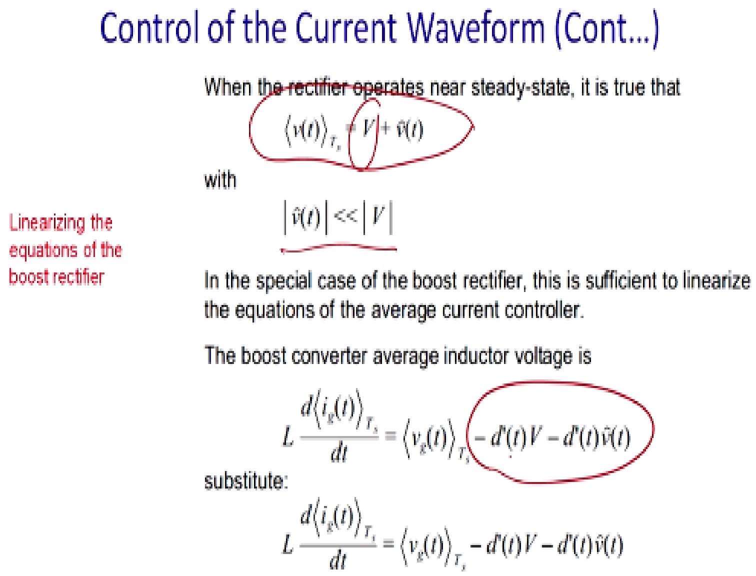

Now let us see that how can we operate it. When rectifier operate near to the steady-state then we can say that actually we have given a very small perturbation or disturbance. So v Ts will be actually the vt that is actual value+ delta vt. So we will say that actually this delta vt is much, much less than this is actually the mod vt. In this case of the boost rectifier is sufficient to linearize this equations for the average control.

So we can linearize it so we differentiate it with its neighborhood of the capital V. So v L di dt=vg-of this differentiation. So to substitute it you know you get actually this value of v delta and d delta.

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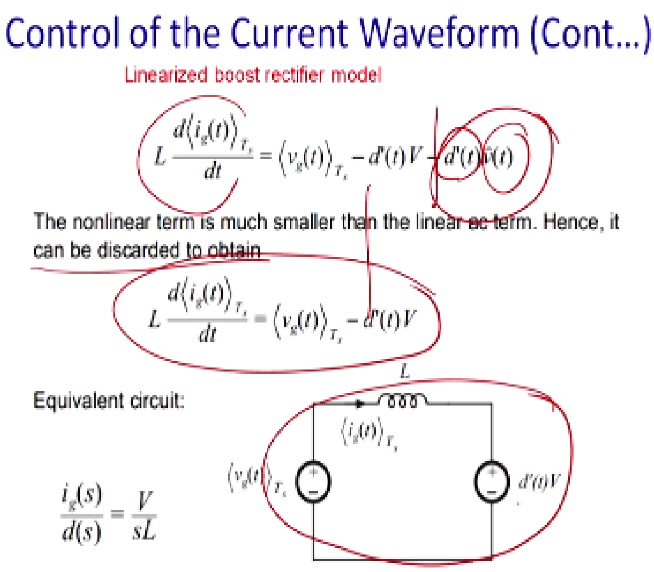

Thereafter we can get actually L did t=this value much smaller than the linear ac term. Hence it can be discarded and we can basically this values because it is a variation of D and variation of del v. This quantity is also small and this quantity is also small. So thus we can neglect this smaller quantities and ultimately you can discard this linear equation comes out to be this and thus your circuits equivalent circuit you can write ig s/ds=V/sL.

So you got this kind of circuit. So it is multiplied by dt*v so this becomes a equivalent circuits.

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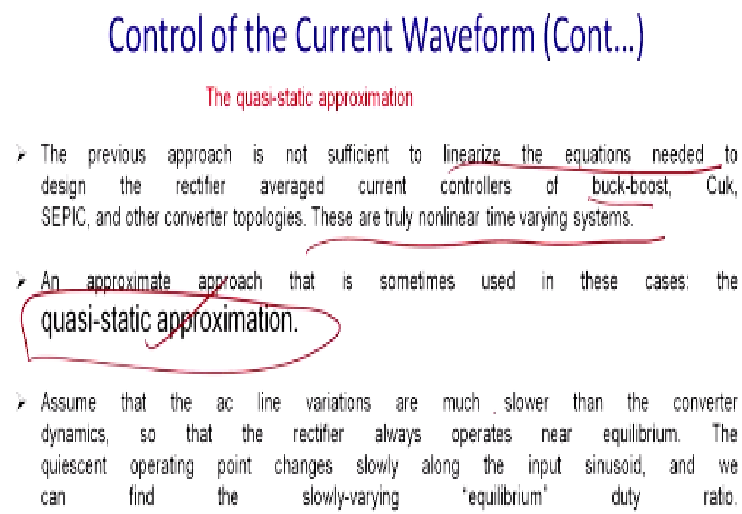

So the previous approach is not sufficient to linearize that is what I am telling linearize the equation need to design the rectifier average current control of buck boost, Cuk, SEPIC and other converted topology. These are truly nonlinear time varying system so we will come later and approximation approach is sometime is used these cases are the quasi-static approximation we will come to the quasi-static approximation now.

Assume that that the ac line variations are much slower because your switching frequency is in a range of the 10s of kilohertz whereas your supply frequency is 50 hertz. So any change in basically the any operation in the range of the switching frequency with respect to that we can suitably assume that the even though it is a varying sinusoidal wave is almost constant within the short duration of time.

So that is called quasi-static approximation and we can find the slowly varying equilibrium duty that is whole about it because this is the phenomena this is 10 milliseconds and so and your switching frequency is of 10 kilohertz that is when it is actually 100 microsecond. So if it is a 100 microsecond so what will happen actually it is 1 10 to the power -3 times of it. So within that 10 to the power- actually if you can consider that within actually 10 to the power 100 microsecond.

So you can assume that that these value is linearized and this valued is almost vc.

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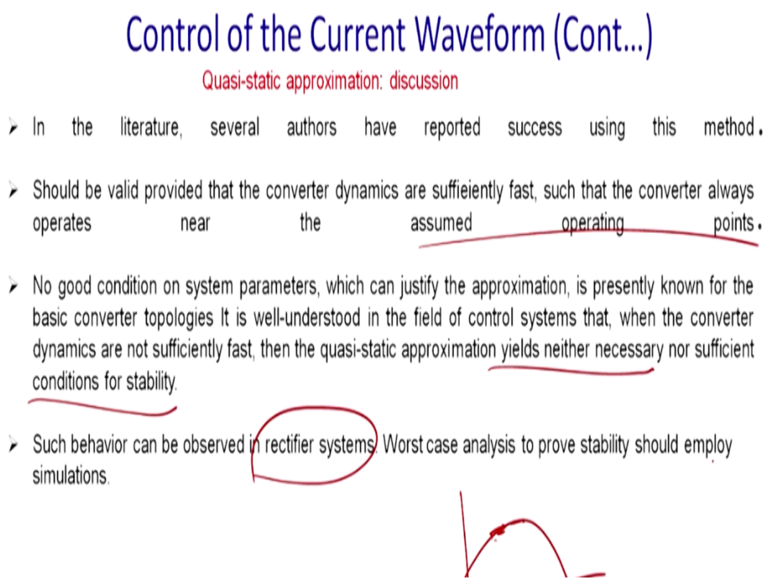

In the literature several authors are reported a success of using this method. So you can refer to the paper and datasheets of the active boost rectifier. So you can find many reported journals it should be valid to provide that the converter dynamics is sufficiently fast such that converter always operates near to the assumed operating point. No good condition on the system parameter which can justify the approximations is presently known for the basic converter topology.

It is well understood that the field of the control system that when the converter dynamics are not sufficiently fast then the quasi-static approximation yields neither necessary not a sufficient condition for the stability. So if you increase the switching frequency of the supply then quasi-static model may not actually predict your stability and other condition according to the control system.

Such behavior can be observed in rectifier system. Worst case analysis to prove stability in a stability should employ by simulations. So you have to do the simulations and find it out the system is stable or not in worst case.

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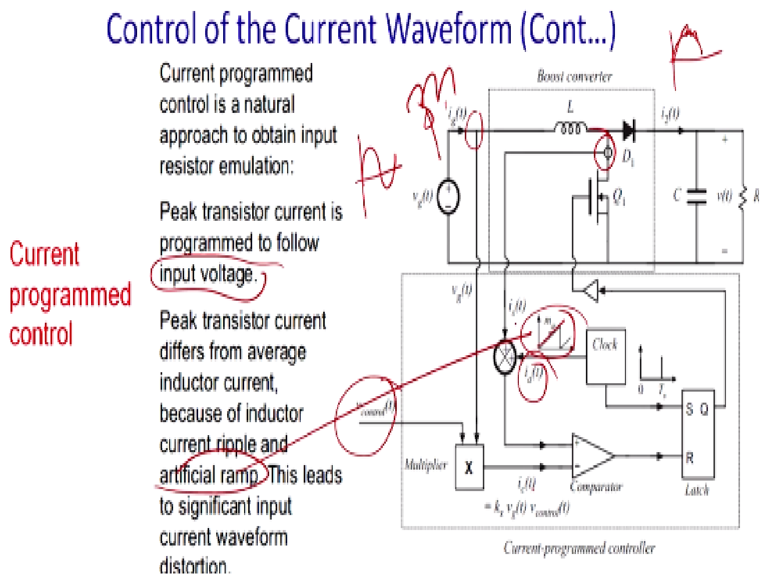

Now the control of the current waveform this is something we required to understand. So current controlled another way of actually monitoring we have seen the average current mode control. We have also another mode of control that is current program control. So what happen you know got a vg that is a ripple RC coming from the rectifier boost topology. Essentially you sense the current by (()) (24:04) sensor.

And what happen here you have vt control and you will get an input so you can multiplier. So you got basically essentially ripple kind of thing. So thereafter mostly what happen this control can be also positive or negative. So make it you know this current like this some chip uses that. So then what happens you actually then sense this current and ultimately you have a Feedforward ramping block.

So what happen here you basically ramp on the current and it will check basically the clock pulses and so you will take a input of ia for this interval of time. This is basically a time integration thus actually it will vary and so ultimately it will add on. So this current and this ramp on basically will be compared with the reference current that will be set by essentially a kx*vg so that is compensating current ic then it will be compared with an op-amp.

And when this actually this current actually rises above this or there is a pattern you try to cross this pattern then it will reset the clock. Thus the output of the switch will be off again current will come down again same cycle will be repeated that is called control current waveform mode and you have inherently you have done the short circuit protection here that is one of the biggest advantage of it.

So you have a ramp control and thus you got a short circuit potential sometime it is also called the peak current mode control. The current program control is a natural approach to obtain the resistors emulations. So as if the system is connected with the resistors. The peak transistor current is program to follow the input voltage which is very built in nature. The peak transistor current differ from the average inductor current.

Because of the inductor current ripple and the artificial ramp added here. This leads to the significant input current distortion. So for this reason we require to plan it accordingly. So this distortion it is sometimes actually leads to the malfunctioning of this devices, but there is 2 advantage of this system. We shall see that later actually this reduces the order of the system.

Ultimately if you have a second order system it can be under damped, over damped or critically damped, but if you have a first order system it is naturally damped. So for this reason you have a added advantage here.

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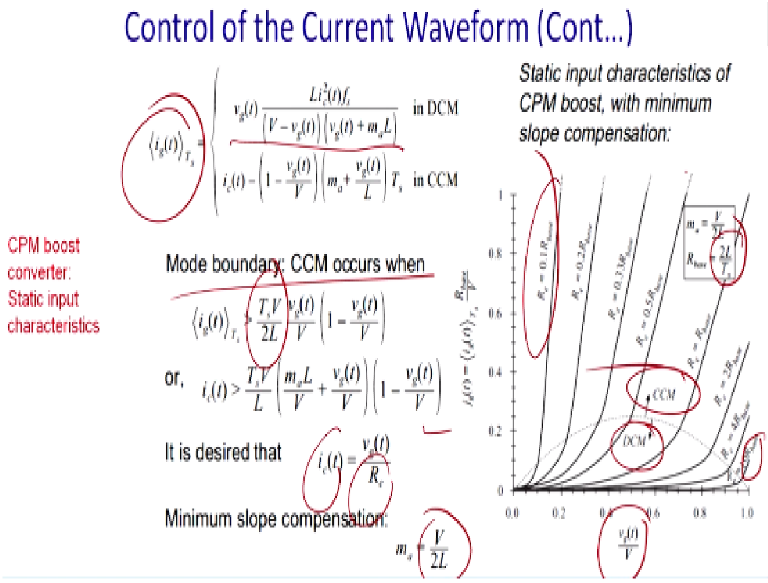

So this ig t what you are talking about may have operated in a CCM mode or in a DCM mode. So this is the value in case of this actually in DCM mode that is i Lc square f vg-this thing and in case if it is in CCM mode so value will change by this and CCM boost converter will have this boundary condition. So ig Ts should be more than to be a in a continuous conduction mode is that Ts V/2L.

This is something like the system parameter you are choosing the system frequency the supply voltage vs vg/V or we can approximate like this. So it is desired that basically i c should be actually vg/effective resistance and Re and multiple slope compensation ma essentially we require to figure it out like this. So that value ma which you are setting that will actually otherwise it will lead through a distortion.

So these we try to compensate the continuous mode of operation. Ultimately ma will be v/2L. As we have seen the previous case same way this is the contour of the DCM and this is the contour of the CCM for various values of the Re. Now when actually it is quite low load. So actually we will find that it will go this actually CCM mode at this point of time where this ratio vg/V will be close to one.

So for this reason operating this actually in a continuous conducted mode for a low load is extremely difficult. Gradually when you have a very high load Re=0.1 of the R base. So there what you can find that actually you have a almost continuous conduction mode started and you will find easier to operate and R base is essentially is the 2L/Ts so this the value of R base.

So this is a characteristics of operations of the CPM mode boost converter characteristics. So we shall continue with the PWM Rectifiers and some technique on the power factor corrections in our next class. Thank you for your attention.