

CHARGING INFRASTRUCTURE

Prof. Apurv Kumar Yadav

Department of Electrical Engineering

Indian Institute of Technology Roorkee

Week-06

Lecture-27

Lec 27: Closed loop control of three-phase AC-DC converter-II

Hello everyone, welcome to the lecture number 27 of this NPTEL lecture series on charging for structure and we have discussed some part related to closed loop control and let us continue our discussion in this lecture as well. So, our control objectives were to regulate the output voltage to a desired value and at the same time we would like the current which is drawn from the source to be having a unity power factor So, that means I mean we do not want any phase angle between the current drawn and the voltage of the AC voltage source. So, this is the requirement.

Now, in this we have seen that since to have the balanced three-phase operation this $i_{sa} + i_{sb} + i_{sc} = 0$ that for balanced three-phase operation. not in order to if you would like to if you want to have that then we could not able to control them independently that means if we are changing the i_{sb} value automatically i_{sa} and i_{sc} value will change and if you trying to change the C value i_{sa} and i_{sb} will change and whenever you are changing the i_{sa} value i_{sb} and i_{sc} will be changing. that is why we need mechanism by which we can make the independent control of those currents in the three phases and for that we have defined you know we have defined the space vector which is nothing but a vector which is rotating in a space with the same frequency as that of the frequency of variation of voltage i mean with respect to time so this space vector is the vector in the spatial domain that means in the space it is rotating and that speed with which it is rotating is same as that of the speed with which voltage is changing over the time t and there we have seen that since the space vector is rotating in a two-dimensional space we need to provide the representative vector and those representative vectors should be such that they are

90° apart from each other and if they are 90° apart from each other then we can ensure that the component of the space vector on those representative axes are independent of each other and then we can control

them or we can change those values those common those representative axis component and that is when the change in one of the component will not have any impact on the other axis component. So, to do that we have defined two reference frames and in that reference frame first one is the alpha beta reference frame which is nothing but the stationary reference frame and the name itself says that α and β are stationary and so this space vector is rotating however the α and β components are stationary with respect to this space vector and that's when the component of space vector on the α axis and on the β axis are actually independent of each other that means when you are changing anything on the α component there is no impact on the β component and whenever you are changing the β component there is no impact on the alpha component primarily because when you take the β axis component onto the alpha axis component you will do $V \beta$ or $V_s \beta \cos 90^\circ$ because they are 90° apart and $\cos 90^\circ = 0$. Similarly, we have defined another reference frame which is rotating reference frame and why the name rotating reference frame because we have assumed that that rotating reference frame are aligned along the space vector which itself is rotating with the speed ω .

So, that is when the name comes dq d means direct axis q means quadrature axis they are 90° apart from each other and d axis is aligned along one of the space vectors. And they will be aligned during the entire operation of the converter or you can say that during the entire line cycle of the voltage variation or you can say the current variation. So, now we have also taken at any given instance of time if a,b,c are sampled quantities and sample quantity could be you know your V_s quantity or the supply voltage three phase supply voltages your sample quantity could be I_s quantity which is the current drawn from the supply and your component could be v_{conv} which is nothing but the voltage which is the applied at the output of the half bridges. And let us see one more example where let's say this is your A axis this is your B axis and this is your C axis and if you define the α β -axis So, α is along is aligned along the place where you will have the 'a' axis peak and then you have the β component which is 90° for me from it and let's

say the vs vector is somewhere your your \vec{V}_s is somewhere let us define this as \vec{V}_s let us take your \vec{V}_s is somewhere here you know and that this is at let's say at given you know let's say this is θ_2 which is at given instance time T2 and this rotation is you know the angle at any given instant time T2 this is $\omega = 2\pi f_s$

So, now this is let us say this is your \vec{V}_s . So, now let us define our dq component if we try to define the dq component. Now we know that our d axis component is always aligned across the along the \vec{V}_s . So, our d axis component d axis is here and the quadrature axis is 90° . Let us draw the 90°

So, this is q component and this angle is nothing but 90° . So, this is how in the entire line cycle this dq axis which are 90° separated from each other will be rotating in the space going from 0° to coming back to the 360° . And this is why it is called as a rotating reference frame sometimes also called as a synchronous rotating frame because they are also rotating with the same speed as that of the speed with which the voltages are varying over the line cycle. And that is when we can define that this quantity. So, similarly following these formulas we can also define $V_s \alpha$, I mean the component of V_s space vector along the alpha axis $V_s \alpha$ is nothing but $\frac{3}{2}V_s$, a which is the sampled a phase voltage value $V_s \beta$ is nothing but you know $\rho \frac{3}{2}V_{sb} - \rho \frac{3}{2}V_{sc}$ where you can say V_{sa} V_{sb} V_{sc} are the sample $V_{an}(t)$, $V_{bn}(t)$, and $V_{cn}(t)$, one of the time instance. Similarly, we can define

$$V_{sd} = V_s \alpha \cos \theta + V_s \beta \sin \theta$$

$$V_{sq} = V_s \alpha \sin \theta + V_s \beta \cos \theta$$

so, we can also sample our this i_{sa} , i_{sb} , i_{sc} current

$$i_{s\alpha} = \frac{3}{2}i_{sa}$$

$$i_{s\beta} = \frac{\sqrt{3}}{2}i_{sb} - \frac{\sqrt{3}}{2}i_{sc}$$

we can and then define is alpha to be $\frac{3}{2} i_{sa}$ is beta to be $\frac{3}{2} i_{sb}$ and then minus $\frac{3}{2} i_{sc}$ where i_{sa} i_{sb} i_{sc} are the sampled i_{sa} i_{sb} i_{sc} currents and similarly you can also define i_{sd} to be $i_{sa} \cos \theta$ and i_{sq} to be $i_{sa} \sin \theta$ and i_{sb} i_{sc} to be $i_{sb} \cos \theta$ and $i_{sb} \sin \theta$ and i_{sc} to be $i_{sc} \cos \theta$ and $i_{sc} \sin \theta$

$$I_{sd} = I_s \alpha \cos \theta + I_s \beta \sin \theta$$

$$I_{sq} = I_s \alpha \sin \theta + I_s \beta \cos \theta$$

and then similarly on the same line if we assume the we are applying the v_{conv} voltage from the converter side on the same line we can also write down our $v_{conv,\alpha}$ $v_{conv,\beta}$ $v_{conv,d}$ and $v_{conv,q}$ component here θ is equals to ωt where t is the time instant when the samples are taken Now, let us try to model this converter in the dq axis or in the $\alpha \beta$ axis frame or synchronous rotating reference frame or stationary reference frame. Now, before that let us try to also define one more thing in this particular converter we have assumed there is also a small resistance which is introduced because of this winding of this inductor and this is nothing but the series resistance of inductance caused due to you can say you can say that caused due to winding resistance you can say winding resistance generally the inductors are bounded over the core so that it has the winding resistance these values are very small in milli ohms so now let us draw single phase equivalent of this one so if you draw the single phase equivalence of this so what we have is again in fundamental frequency terms fundamental frequency.

So, what we have is we have $V_s(t)$, we have L_s or we have L and we have R_s and then on the other side we have applying $v_{conv}(t)$. and there will be the current is of i current which is being drawn from the source i mean obviously for the fundamental frequency component so now using this let us try to draw you know in the vector terms let us try to draw this one in the vector terms we can say this is nothing but the v_s space vector we have i this is i_s and then this is another thing which is v_{conv} space vector and then you have i space vector now this space vector this v_s is v_{conv} is actually the combined effect of all the three phases which we are talking about So, now what we have is, let us try to draw using this thing. So, what we have is we have alpha axis, we have beta axis, which 90° from each other.

So, we have α β components, and then we will define our space vector \vec{V}_s . Let us say at some angle, which is angle theta, let us say this is a theta angle, which is being drawn. And we know that we have v_{conv} space vector, \vec{V}_s space vector, and we have \vec{I}_s space vector. We have these three quantities which we have to draw. So, let me define this: the d-axis is placed over here, and we have, you know, our q-axis. which is placed over there, and these two are 90° from each other.

So, we have taken, we have aligned our d-axis along this \vec{V}_s because we know that the supplies, I mean, a, b, c phase voltages which we apply are the ones which are constant in a system. However, this I_s , I mean, the current which is drawn from the source depends upon the operation of this converter, and the v_{conv} which is applied is again dependent on the operation of the converter. It's only the \vec{V}_s space vector which remains mostly constant and mostly fixed over the operation of the converter since they are the supply voltages, and we assume the supply voltages will be having balanced operation as well as the RMS values and peak values will be constant over the line cycle. So, it is one of the things with which we can take the reference. It has minimal deviation, so that's why we have aligned our d-axis along the \vec{V}_s space vector, and that's when we define our q-axis perpendicular to that. So, that means if we make this d-component align along these \vec{V}_s space vector, then we can ensure that the component of \vec{V}_s space vector along the d-axis is non-zero.

However, the component of \vec{V}_s space vector along the q-axis is zero, and that is when if we can ensure that this $V_{sq} = 0$ is zero, that is when we are ensuring that our d-axis is aligned along the space vector V_s . Now, this space vector is at angle theta and which is defined as ωt . And let us define our v_{conv} space vector. Let us define that v_{conv} space vector at some angle. Let us define this as v_{conv} space vector, and that is, let us say, at angle Δ . I mean, this could be this side; this could be another side.

I mean any side it could be. In general, let us define this as at an angle delta. Similarly, we can also define you know space vector is or the current which is drawn from the source. So, this is space vector will be let us say define it as let us say here. However, we would like to ensure that is vector to be aligned along the \vec{V}_s but for a general case. Let us say this one is at \emptyset angle at some point of time, let us take this we have some phase angle however this this is not we want to do in our operation but for general case let us define one quantity \emptyset which is a phase angle between is space vector and the \vec{V}_s . Now, if you look very carefully in this particular space vector diagram, let us try to find out the alpha beta components and the dq component and that is when we can define our models in the dq axis frame and $\alpha \beta$ axis frames. So, let us try to write down the \vec{V}_s , in dq axis terms. So, we can define I mean for dq plane or dq axis plane we can define my $V_{s,phasor}$ is nothing but component of along the d axis the component of Vs along the d axis +. Since this two d and q are 90 degree apart from each other so we will write j, 0, j corresponds to 90° . So, there is no V_{sq} component because our V_{sq} component is equals to 0. Why I can say q component is 0? As the \vec{V}_s is aligned along d-axis. During operation, we will ensure that this dx is aligning along the space vector Vs. Now, let us try to write the Vs space vector in terms of polar formation.

So, it is magnitude of \vec{V}_s raised to power 0. So, modulus is nothing but you can say modulus

$$|\vec{V}_s| = \sqrt{V_{sd}^2 + V_{sq}^2},$$

which is 0 under root. And there is since there is no Vsd vector. So, we can say it is angle 0 with respect to d axis. Similarly, we can write $\alpha \beta$ frame.

We can write this is also we can write I mean plain you can say dq frame to be more precise.

So, for alpha beta plane, we can write $\vec{V}_s = |v_s|$. So, the magnitude will remain be the same

of this vector because we have seen in the 360 period the magnitude of this \vec{V}_s will remain be

the same so the amplitude will remain be the same however the angle to which this $\alpha \beta$ axis away from this dq is there. So, we will represent since we are representing with respect to alpha

beta plane it will be e raised to power j theta and that θ comes from the angle between dq. So,

whatever my V_{sd} component is there, I will just take V_{sd} component $\cos \theta$ to get the $V_{s\alpha}$

component and V_{sd} component $\sin \theta$, I will get the $V_{s\beta}$ component. However, there is no V_{sq} component, so that is 0.

Now we can also define for another quantities in the same line we can define our is space vector to be modulus is e raised to power you know the angle with which it is with respect to $dq = j\phi$. Similarly, we can write $\vec{v}_{conv} = |v_{conv}| e^{j\Delta}$, and 'e' raised to power $j\Delta$.

Similarly, for $\alpha \beta$ plane we can write \vec{I}_s to be modulus is 'e' raised to power it is from $\alpha \beta$ it is $\theta + \phi$, so $e^{j(\theta+\phi)}$. And we can say \vec{v}_{conv} to be $|v_{conv}| e^{j(\theta+\delta)}$, You can say angle wise if you see it is $\theta + \delta$. So, it is $\theta + \delta$.

$$\vec{I}_s = |I_s| e^{j(\theta+\phi)}$$

$$\vec{v}_{conv} = |v_{conv}| e^{j(\theta+\delta)}$$

And this is the way by which we can move from one frame to another frame and from another frame to that frame. And if you look very carefully, the magnitude of the space vector is not changing. The amplitude will remain the same. However, the angle for those frames will be different. So here, if we take the $\alpha \beta$ plane, we can say, for example, if we write $I_{s\alpha}$, it will be nothing but the modulus of $I_s \cos(\theta + \phi)$, and I can write the β component $I_{s\beta}$ to be the magnitude of $I_s \sin(\theta + \phi)$.

So, those sine and cosine terms will actually give you different values. And now, using this representation, let us try to obtain the single-phase equivalent circuit model in the alpha-beta and dq frames. Because if we model that circuit in the alpha-beta frame and dq frame, we can obtain the α , β , d, and q components of currents and then control those components independently.

So, let us try to write down our equations first in the stationary frame, and then from the stationary frame, we will move to the rotating reference frame. So, let us try to write down the

circuit model in the $\alpha \beta$ stationary frame. So, if we apply KVL, it is nothing but, you know, we can write the

$$\begin{aligned}
 \vec{V}_s &= L \frac{d\vec{I}_s}{dt} + R\vec{I}_s + v_{conv} \rightarrow \\
 \vec{V}_s &= v_s e^{j\theta} \\
 \vec{I}_s &= |I_s| e^{j(\theta+\phi)} \\
 v_{conv} \rightarrow &= |v_{conv}| e^{j(\theta+\delta)} \\
 V_s e^{j\theta} &= L \frac{d}{dt} |I_s| e^{j(\theta+\phi)} + R |I_s| e^{j(\theta+\phi)} + |v_{conv}| e^{j(\theta+\delta)} \quad (1)
 \end{aligned}$$

So, this we got our $\alpha \beta$ stationary frame. now let us move this term to the dq rotating frame so let us write dq rotating frame or synchronous rotating frame. Let us write now this we will get let us say this is the equation number one this we will get by multiplying equation number 1 by because what we are doing we are just shifting that $\alpha \beta$ frame equation to the dq frame equation and that we will get by subtracting the angle θ in all the vectors, so all the angles correspond to the vectors are subtracted by angle θ . So, we will get it by multiplying equation 1/ $e^{-j\theta}$.

$$\begin{aligned}
 V_s e^{j\theta} \cdot e^{-j\theta} &= V_s e^{j(\theta-\theta)} = V_s e^0 = V_s \\
 V_s e^{j\theta} \cdot e^{-j\theta} &= e^{-j\theta} \left[L \frac{d}{dt} |I_s| e^{j(\theta+\phi)} + R |I_s| e^{j(\theta+\phi)} + |v_{conv}| e^{j(\theta+\delta)} \right] \\
 &= L \frac{d}{dt} \left(|I_s| e^{j(\theta+\phi)} \right) e^{-j\theta} \\
 &= e^{j(\theta+\phi)} \cdot e^{-j\theta} = e^{j\phi} \\
 R |I_s| e^{j(\theta+\phi)} \cdot e^{-j\theta} &= R |I_s| e^{j\phi} \\
 |v_{conv}| e^{j(\theta+\delta)} \cdot e^{-j\theta} &= |v_{conv}| e^{j\delta} \\
 V_s e^0 &= \left[L \frac{d}{dt} \left(|I_s| e^{j(\theta+\phi)} \right) e^{-j\theta} + R |I_s| e^{j\phi} + |v_{conv}| e^{j\delta} \right] \quad (2)
 \end{aligned}$$

and this one, this can be easily come inside the bracket. So, that will become modulus I_s e raised to power $j\theta$. $\theta + \phi - \theta$. So, that will be $j\phi + E$ converter E power. See, these are the exponential, you know, this angle term.

$$\vec{I}_s = |I_s| e^{j(\theta + \phi - \theta)} = e^{j\phi}$$

So, they will be just multiplication will be added. So, $(\theta + \phi - \theta)$. So, that will be just δ . And now, if you look very carefully at equation number 2, okay, this is the term which has to be further segregated because this is not inside the $\frac{d}{dt}$ term.

This is the term which is actually varying with time. It has the magnitude along with this, and it has the angle term. We know that this angle term, this θ , changes with time because we know that our $\frac{d\theta}{dt} = \omega$.

So, that term will come into the picture. So, that is why we just cannot take directly this $e^{-j\theta}$ inside. So, let us represent this term in some other way. So, let us try to write down these terms in this way, this particular term, simplifying this term. So, for that, let us take one term $L \frac{dI_s}{dt} e^{-j\theta}$.

This we are taking now. This term now we can define this term to be u and this term to be v . So now there are two terms, and both the terms are dependent on time, so we will use the differentiation of the product of the terms. So what we will get is we will get L coming out first. You write d by dt e power $\theta + \phi$. And this is e power minus $j\theta + e$ power $j\theta + \phi$ to d by dt of e power minus $j\theta$.

$$L \frac{d}{dt} \left(|I_s| e^{j(\theta + \phi)} \right) e^{-j\theta}$$

Now, this term, if we see here, we can write this one as, you know, let us take the next exercise, which is $L d$ by dt . $\theta + \phi$ and θ are to be equal to, we can take L . We take this one out $L d$ by dt is e power e power $j\theta + \phi$ e power minus $j\theta + e$ power $j\theta + \phi$.

$$L \frac{d}{dt} \left(|I_s| e^{j(\theta + \phi)} \right) e^{-j\theta} = \left[L \frac{d}{dt} \left(|I_s| e^{j(\theta + \phi)} \right) e^{-j\theta} + |I_s| e^{j(\theta + \phi)} \frac{d}{dt} e^{-j\theta} \right]$$

Now we can write

$$\frac{d}{dt} e^{-j\theta} = e^{-j\theta} \left(-j \frac{d\theta}{dt} \right), \frac{d\theta}{dt} = \omega$$

Now this, when we put this eq. (1) here, we will get

$$\frac{d}{dt} e^{-j\theta} = -j \omega e^{-j\theta}$$

and here again (1) is come inside will come inside. This will be there now. This we can rearrange this term and this term, so what we will get (1),

This will go that side is nothing but L modulus of $\vec{I}_s e^{j\theta}$ space vector e power j. Now this we can take it inside j theta Phi minus theta. +, because it is inside the bracket, we can take before that we have just represented in this manner, and this goes there so that will be l is e power j theta + phi minus theta because this this will go inside the this one into w and that we can say l is e power j theta + phi, minus theta is nothing but l so phi is e power j phi + l w.

$$L \frac{d}{dt} \left(|I_s| e^{j(\theta+\phi)} \right) e^{-j\theta} = L \frac{d}{dt} \left(|I_s| e^{j(\theta+\phi-\theta)} \right) + jL\omega \left(|I_s| e^{j(\theta+\phi-\theta)} \right)$$

$$L \frac{d}{dt} \left(|I_s| e^{j(\theta+\phi)} \right) e^{-j\theta} = L \frac{d}{dt} \left(|I_s| e^{j\phi} \right) + jL\omega \left(|I_s| e^{j\phi} \right) \quad (3)$$

$$(\theta + \phi - \theta) = \phi$$

This θ will get cancelled only ϕ is $e^{j\phi}$. And if we look very carefully, this is nothing but equation 3. So, put equation 3 in 2.

$$V_s e^0 = \left[L \frac{d}{dt} \left(|I_s| e^{j\phi} \right) + R_s jL\omega \left(|I_s| e^{j\phi} \right) + R |I_s| e^{j\phi} + |v_{conv}| e^{j\delta} \right] \quad (4)$$

$$|I_s| e^{j\theta} = |I_s| \cos\theta + j |I_s| \sin\theta = I_{sd} + j I_{sq}$$

$$V_s e^{j\theta} = V_{sd} + j0, (V_{sd} = |V_s| \cos\theta)$$

Similarly, we can write down for

$$|v_{conv}| e^{j\delta} = |v_{conv}| \cos(\delta + j) + R_s j |v_{conv}| \sin\delta = v_{conv,d} + j v_{conv,q}$$

So, this we can see. This v_{conv} , if we take the v_{conv} component, let us take the red color, so if we take this this, you know, this v_{conv} , this is but v_{conv} , d component is nothing but $|v_{conv}| \cos \delta$, and this will be taken on Q component.

So, this is nothing but v_{conv} over q component, and that is nothing but magnitude of $v_{conv} \sin \delta$ and that is what we have written over there. $v_{conv} \sin \delta$ is nothing but v_{conv} , q component. So, now let us take this particular equation, equation number 4, and try to write it down in terms of D and Q components.

$$V_{sd} + j0 = L \frac{d}{dt} (I_{sd} + jI_{sq}) + R_s jL \omega (I_{sd} + jI_{sq}) + (v_{conv,d} + jv_{conv,q})$$

$$V_{sd} + j0 = L \frac{d}{dt} I_{sd} + jL \frac{d}{dt} I_{sq} + R_s I_{sd} + R_s jI_{sq} + v_{conv,d} + jv_{conv,q} + jL\omega I_{sd} - L\omega I_{sq}$$

And since this d and q axis are 90° apart from each other, so we can separate out this d component and q component, d axis component and q axis component to get the d axis model and q axis model.

So, then we can write, we can separate out real and imaginary part. When we separate our real and imaginary part what we will get with just the real part

$$V_{sd} = L \frac{d}{dt} I_{sd} + R_s I_{sd} + v_{conv,d} - L\omega I_{sq}$$

similarly, imaginary part

$$0 = L \frac{d}{dt} I_{sq} + R_s I_{sq} + v_{conv,q} + L\omega I_{sd}$$

what we can do is we can rearrange this term. actually get so if you rearrange this term so it is the v_{conv} , and q converter which you are applying so when we write down these things what we will get is you know $L \frac{d}{dt} I_{sd} + R_s I_{sd}$ if we take to the other side $- v_{conv,d} + L\omega I_{sq}$ and + vst and similarly $L \frac{d}{dt} I_{sq} + R_s I_{sq}$ that is nothing but minus $- v_{conv,q} - L\omega I_{sd}$.

Now if we look this one this is nothing but the d axis model and this is nothing but the q axis model. These two parts. And here we are applying the, you know, the voltages across the L

and R_s . And what we see is that in the d axis model, all the terms are d axis except one term, which is this one.

And that is the cross coupling term. Similarly, in q-axis model all the components are q component except this term which is the cross-coupling term. So, then whenever we are making the closed loop control we must ensure that this cross coupling term need to be properly managed uh we will discuss that when we discuss the closed loop control but what you see is that we have derived the two axis model where we are applying two voltages from the you know we are applying the d-axis we converted d-axis and we have the supply voltage v_{hd} along the L and r_s along the inductor and resistance while in the q-axis we are applying q component of the converter and the q component of v_s space vector is zero so what we see is that we will define the two axis model and now in this one if we are changing this i_{sd} there is no impact to we see on the i_{sq} and if we are changing the i_{sq} there is no impact on i_{sd} because this i_{sd} and i_{sq} components are 90° apart from each other because these are component of

current space vector along the d-axis and q-axis so they are 90° apart from each other because d and q-axis are 90° apart from each other and then when you are changing the i_{sd} component there is no impact you will see in the i_{sq} component and whenever you are changing the i_{sq} component there is no impact you will see on the i_{sd} component and that's when we can get two independent circuit models which is d-axis model and q-axis model And then we can then control this $v_{conv,d}$ along the d axis and $v_{conv,q}$ along the q axis and thus you can able to control the I_{sd} and I_{sq} and this control is independent of each other because d and q are 90° apart from each other. So, with this we will get the independent control over the you know two phases you can say two two different axis we can get the independent control on two currents and those two currents which is i_{sq} and i_{sd} and $v_{conv,d}$ and $v_{conv,q}$ is actually derived from the three phase quantities and if we are controlling this two phase quantity then accordingly my three phase quantities will be changed and in the the main advantage what we will get is in the d and q axis we have independent circuits so we can control them independently and that's when in the three-phase system we will reflect that independent control in the three-phase by making

sure we have the you know the balanced three-phase operation and because we have derived the q and d components by assuming that we have balanced three-phase operation.

So this d and q axis component whenever we are controlling independently it will actually reflect onto the three-phase quantities in the equal proportional and that's when you can do the independent control on this and we will discuss more inference what we get coming out of this derivation in the next class because that will clear your understanding about how we can do the independent control and how we can say they are independent of each other there is small cross coupling term but this terms can be eliminated in the terms of feed forward terms when you are doing the closed loop control we will discuss those things in the next class so here in this particular lecture we have derived two axis model and d axis model and q axis model and those two axis models are quite independent of each other because the quantities which are used here are independent of each other in both the circuit models and that's when the circuit models are independent of each other we will discuss this in further detail in the next lecture thank you