Power Quality
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Control of DSTATCOM
Lecture - 08
Active Shunt Compensation (contd.)

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Welcome to this course on Power Quality. Last lecture we discussed this custom power devices which consist of DSTATCOM Distribution Static Compensator, DVR Dynamic Voltage Restorer, and UPQC Unified Power Quality Conditioner. And out of that we discussed the configuration of DSTATCOM for single-phase supply system, then the three-phase 3 wire supply system and three-phase 4 wire supply system for compensation with this active compensator.

This DSTATCOM is also called as active shunt compensator, and we like to discuss about the control of this DSTATCOM. There are large number of control algorithm reported in the literature and book, [FL] we will confined some only important control algorithms here that how this DSTATCOM have to be controlled for providing the these required compensation which we discussed in the previous principle operation as well as the design and typically their features like.

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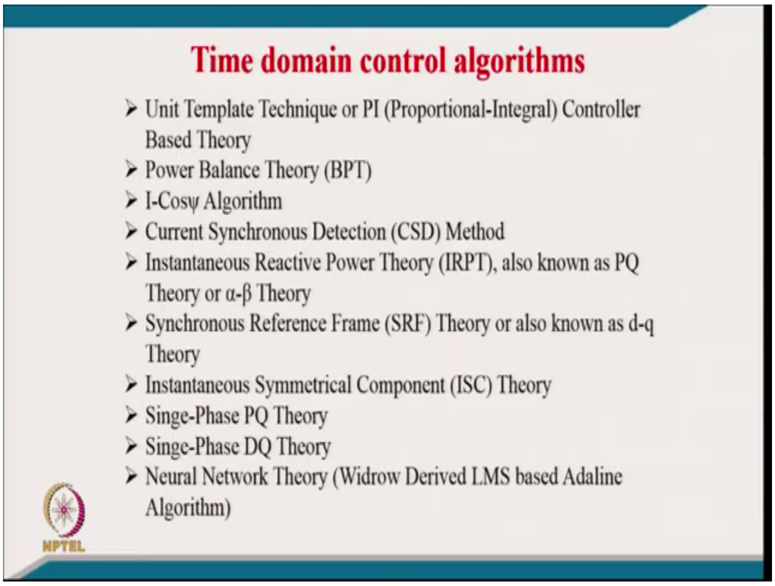

[FL] coming to like the control of three-phase 3 wire system, I mean we have a we divide this control algorithm into two parts which are reported in the literature that one is the time domain control algorithms. I mean we do all estimation only on the basis of time and typically we sense the signal and calculate instantaneously that we call it time domain.

And here we have a plenty of control technique, we call it time unit template or proportional integral control base theory, power balance theory, then I-Cos phi algorithm, the current synchronous detection method, instantaneous reactive power theory also known PQ theory or alpha-beta theory, which is based on clapped transformation on alpha-beta theory, and other then we go to synchronous reference frame theory which is also known DQ theory and based on Park transformation.

And other control algorithm is instantaneous symmetrical component theory based on typically on symmetrical concept. Then, we go for single-phase PQ theory, I mean these are used based on single-phase concept, but applied for three-phase also as well as single-phase. And single-phase DQ theory that also can be applied for single-phase as well as for three-phase.

And then of course, we like to have an example of neural network, I mean especially Widrow Derived LMS based Adaline Algorithm which is one of the simplest algorithm here, but based on the neural network like. [FL], we like to correlate bit you on that.

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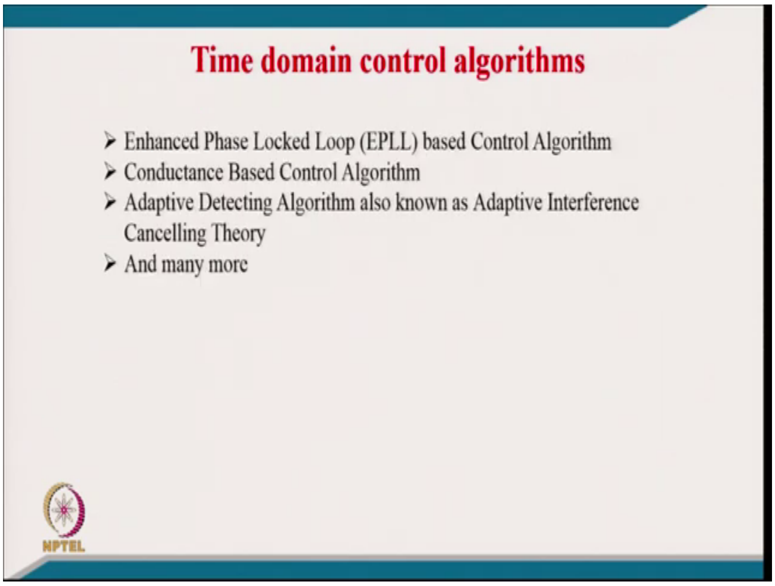

Then, the additional algorithm is enhanced PLL based control algorithm, conductance based control algorithm, adaptive detecting algorithm also known as the adaptive interference cancelling algorithm and many more. [FL] we like to confine of course, these are the just classification of control algorithm. We like to confine the feed just to explain here how we really, I mean can implement and how we can really simulate the whole system with these control algorithm.

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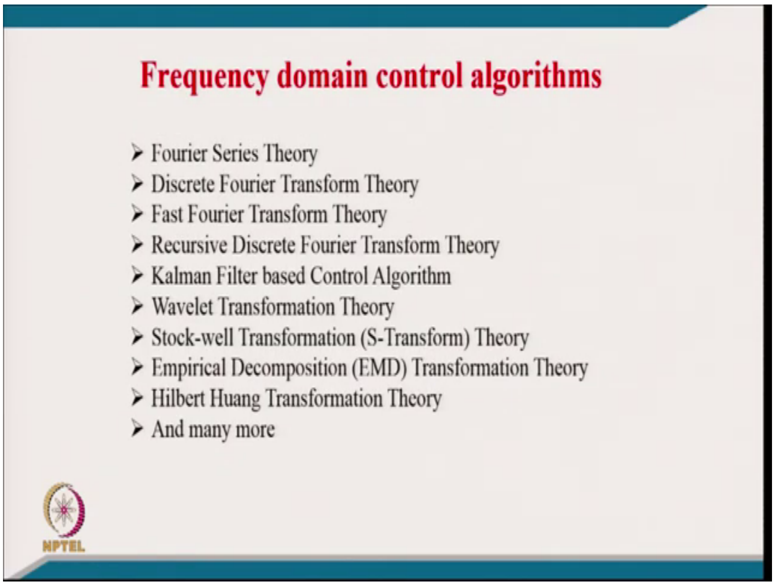

The another set of control algorithm are the frequency domain control algorithm. Frequency domain in the sense that we sense the quantity and we use the typically the frequency transformation like a Fourier series theory, discrete Fourier transform theory, fast Fourier transform theory, recursive discrete Fourier transform theory, Kalman filter based control algorithm, wavelet transformation based theory, a stock-well transformation theory, and empirical decomposition transformation theory, and Hilbert Huang transformation theory.

Of course, most of these frequency domain control algorithms are used normally in the instrument like which have we have shown you like a kind of power analyser. I mean which are responsible to get the total harmonic distortion as well as the typically you can call it the different harmonics in the or reactive power active power all calculation the instrument which are you like we call it power analyser or power network analyser power recorder.

But of course, these some of these algorithms I mean people have modified it because these takes little longer time than time domain algorithm, but people have modified it because now we have a very fast DSP for implementation, [FL] people are able to use these algorithms also. I mean for the control implementation of these DSTATCOM and other active compensators which we like to discuss.

Now, this control algorithm we will now to like to cover in every active, other active compensator, [FL] we like to discuss one.

Only the modification we like to suggest. [FL] this is just like we will like to discuss for maybe for shunt compensator and then we can this modify very quickly for series compensator or maybe a hybrid compensator where our active elements are involved, I mean either in these limbic you can call it the custom power devices or we can even use for this active power factor, active power filters also which we will discuss after that like I mean or so.

Or many case studies also. These control algorithms will remain the same. That is the reason we are going to explore a little bit here more in detail.

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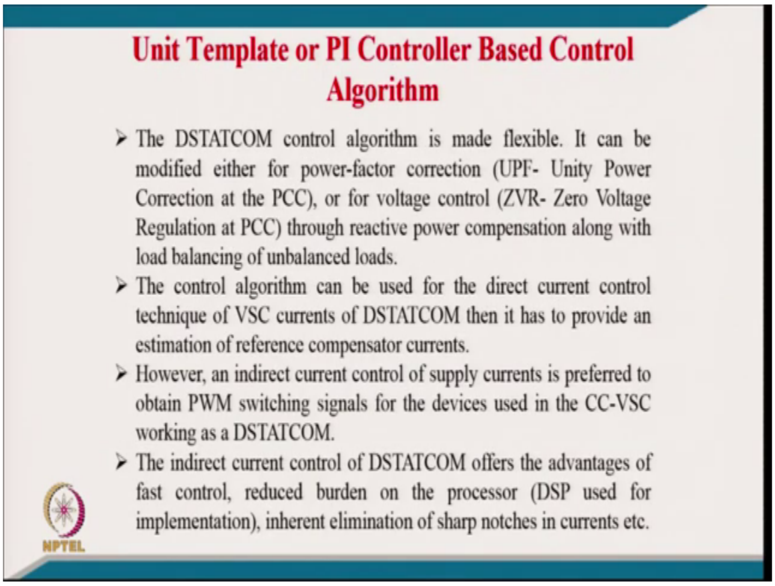

[FL] coming to typically first algorithm which you call it unit templates or PI controller based control algorithm. I mean the DSTATCOM control algorithm is made flexible and it can be modified either for power factor correction, for unity power factor correction at the PCC that is one requirement.

And another requirement of course, we discussed earlier that it can be DSTATCOM can be use all, even for voltage regulation for 0 voltage regulation at through reactive power compensator along with the load balancing of unbalanced load.

[FL] it means you can achieve two, with the help of reactive power you can do either power factor correction to unity or 0 voltage regulation. [FL] this control the algorithms should be modified accordingly. [FL] we like to discuss that what modification are required maybe this modification we like to discuss for typically for some algorithm and for another other algorithm you can do in the similar manner.

[FL] control algorithm can be used for direct current control technique of voltage source converter which are implemented as a DSTATCOM. And then it had to provide an estimation of reference compensator current. Well, this current call it means we have to calculate the reference current of compensator or VSC current, and then we implement current controller.

Well the another; however, an indirect current control of supply current is preferred to obtain PWM switching for the devices used in current control voltage source converter working as a DSTATCOM. The indirect current control algorithm it is mentioned. Why it is preferred? Because the supply current on which you are putting control, they are very slow varying current compared to some time typically the compensator current.

Compensators current some time require very sharp changes, if the load current are having a sharp changes then you require a very sharp changes in the compensator current, and sometime it is difficult [FL] we do compensation typically control on supply current. If supply current is meeting your requirement indirectly you can call it the DSTATCOM is bound to compensate [FL] your requirement of the your load compensation.

[FL] indirect current control of DSTATCOM offers the advantage of fast control, reduce burden on the processor, DSP for implementation, and inherent the elimination of sharp notches in the current if it is there.

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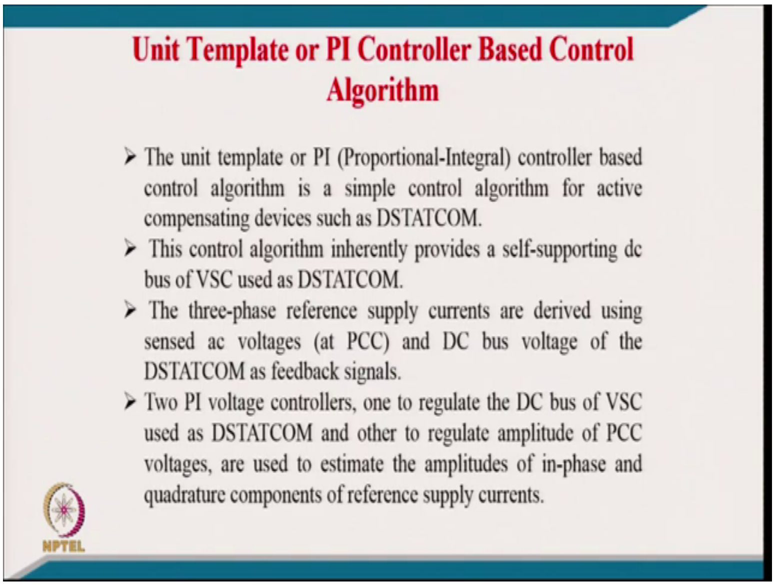

Well, the unit template or PI controller based control algorithm is a simple control algorithm for active compensating devices such as DSTATCOM. And this control algorithm inherently provides a self-supporting DC bus of voltage source converter used as a DSTATCOM. And the three-phase reference supply currents are derived using sense ac voltages at PCC and DC voltage of the DSTATCOM as feedback signal.

The two PI controllers, one to regulate the DC voltage of the DC bus of the VSC used as DSTATCOM other to regulate the amplitude of PCC voltages, are used to estimate the amplitude of in phase and quadrature component of reference supply current like.

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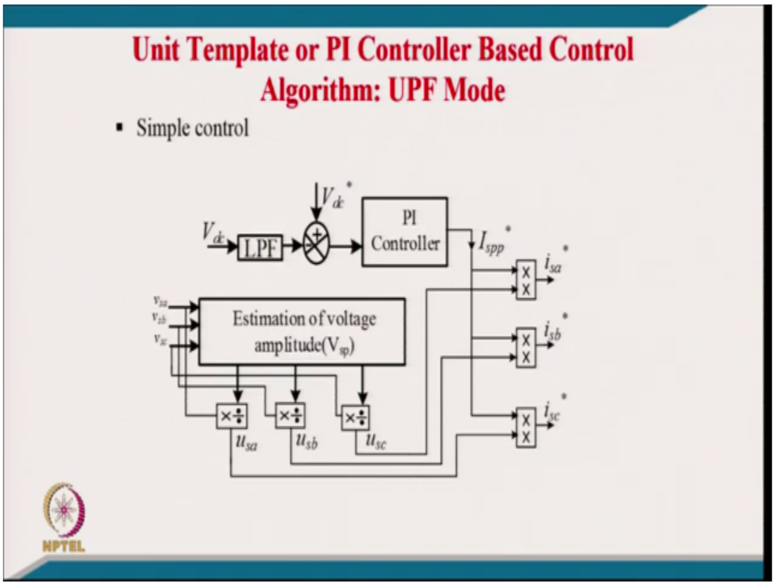

[FL], we will discuss this with this block diagram. I mean you can just see first we like to discuss you know template or PI controller based algorithm for unity power factor control or unity power factor mode of operation of DSTATCOM. [FL] it is a simple control. You can just see here I mean in this diagram, I mean we are typically having a reference DC link voltage which we have already discussed in the design typically. [FL] we have a reference DC link voltage.

Typical example, I have already discussed that 415 volt three-phase supply system this we can take around 700 volt. And of course, the DC link voltage, we sense the DC link voltage, but you can understand if there is any unbalance either in the load or in the voltage the second harmonics get reflected in the ripple at the DC link.

It is a nature of the compensator, because compensator this voltage source inverter or converter have to operate this compensator [FL] that certainly second harmonic or second harmonic ripple will be appear. [FL] then we have to after sensing DC link voltage we have to put a low pass filter to eliminate all the ripple from the DC link voltage, and then we use it to feedback.

And here we use the PI control proportional, integral control a closed loop control; however, you can use any closed loop control like maybe sliding mode controller, fuzzy logic controller or any closed loop controller because we want this DC link voltage should be equal to reference voltage which we have got from design.

And output of this we consider it typically the supply current amplitude because the reason being the power which we are getting as a loss for the compensator voltage source converter because it has a losses in the sense dielectric loss in the capacitor of DC link, you have a losses in the interfacing inductor, you have a loss in ripple filter, you have a loss in inverter or voltage source converter devices.

[FL] all these losses have to be also coming from the supply system as a active power. [FL] that is the reason we consider this as a active power amplitude of it. Now, sensing the supply voltage here, I mean like these 3 supply voltage, we might be sensing the not the phase voltage, we might be sense the line voltage, and from line voltage we have to estimate the typically the phase voltage. That relation also we like to give there.

So, from once moreover this voltage also may be distorted or unbalanced. [FL] it means what; sometime we have to do it we will talk little later I mean at the moment we will not talk about, [FL] after sensing the two line voltage we will convert this into the phase voltage. Then, we like to use the band pass filter whoever getting a fundamental of this, then we can have a positive sequence voltage estimation, and then we will use in this block for getting a amplitude.

[FL] once we get the amplitude we get their instantaneous value. We will divide this, I mean this ref typically the instantaneous voltage by amplitude [FL] we will get a template. These u sa, u sb, u sc are the template in phase with the phase voltage. Keep in mind. And this is unity amplitude because you say just like a sin omega t or sin theta sin omega t minus 120 sin omega t plus 120. [FL] we got the phase virtually from of supply voltage.

Now, we from these phase we multiplied the with the amplitude typically of this current and we get the reference current for the supply because these current reference current are in phase with the voltage. [FL] it means we will be automatically inherently having the unity power factor operation of this compensator, where these currents are in phase with the supply voltage, like I mean.

Well, this reference current should not have any harmonics. We already filtered the DC link voltage and control on DC. And I already explained that this voltage, I mean also we have to filter and we have to take only positive sequence of it, so that these are balance. So, that these templates are also balanced with the unity amplitude like or so.

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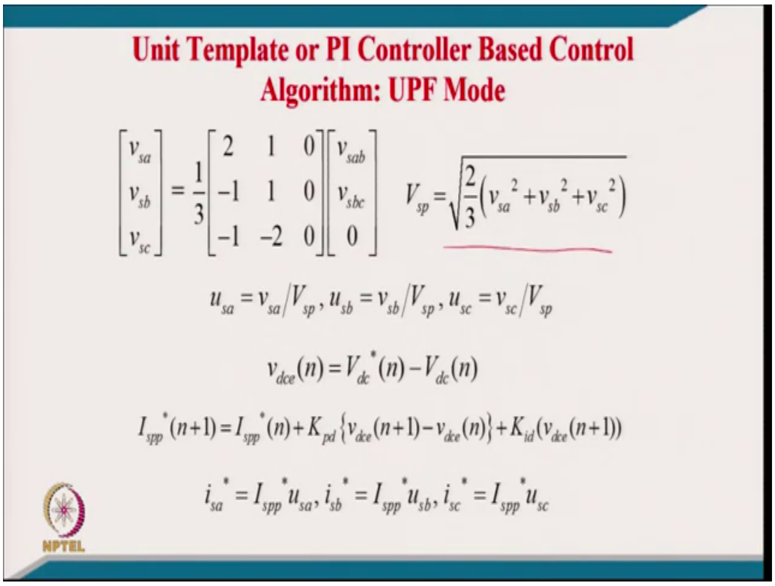

Well coming to typically, I mean these are the expression here you can look into we are sensing already two line voltage. And from two line voltage we can find out the phase three-phase voltage, phase voltage like here. And from this three-phase voltage, we calculate the amplitude from typically from this relation. I mean this is the amplitude of this phase voltage, I mean typically.

How we got it? You can have a three-phase voltage, you square and typically square them [FL] because the phase voltage is nothing but you can call it root two times, ok. Hence, because it is all 3 you get the VSP or p amplitude you got out [FL] that comes 3 by 2, I mean from that relation.

[FL] derivation of this relation we already talk about earlier I mean or so. And from this we get the term typically the template, which we discussed in the previous figure I mean the phase voltage divide by the amplitude, phase b voltage divide by its amplitude phase c voltage divide by, [FL] all these are the template I mean.

And we calculate the dc link voltage error which we have already shown in the previous block. We get the dc link voltage error. This is a reference voltage and this is the voltage after the filtering, low pass filter. Of course, the low; why we have to push low pass filter? Because we want dc component of the dc link voltage, not the ripple out of that. [FL] we get the this error.

And this is the equation of PI controller in digital form I mean like, ok. This is the you can call it the nth plus sample. The this is after nth sample. Keep in mind the PI controller does not know what is the maximum typical current of amplitude you can apply allow in the from the supply or in the compensator. [FL] you have to typically, I mean limit this I mean according to your rating of the compensator and this is virtually the proportional term and this is integral term.

So, from this we get the amplitude for n plus 1. And once we got the amplitude reference we multiplied these template here, three-phase, we get the three-phase instantaneous supply current i sa star, i sb star, i sc star which are in phase with the these supply voltage or you can call it these are in phase with the supply voltage.

Means if these current are controls actual current of supply current are control close to this reference current, we get the unity power factor operation of the these this DSTATCOM like. [FL] that is about typically you can call it, I mean the. [FL] we have to sense the current, I mean that block is not shown here.

We have to, these are only reference current. We have to sense the grid current or supply current and then we have to put a current controller. We will discuss sometime current controller, and what is this current controller? These two current goes either hysteresis controller to give the typically, I mean with the hysteresis band, it give the switching for the inverter devices for all 3 lag phase on a phase, b phase, c phase.

Or we can use any current other current controller. I mean you can use the typically like a proportional PI controller and then PI controller output of course, have to be compared with the your carrier wave of switching frequency. [FL] then you will get a fixed switching frequency of the your DSTATCOM. Otherwise in hysteresis controller switching you can see may vary it, ok or so.

[FL] current controller is not at the moment I explain, but these are the reference current which processor have to do it. And processor, then we have a current controller. Sometime current controller is implemented in the PWM block also separately in the DSP like. We will discuss some time later about that. [FL] that is about the gist of this control algorithm first control algorithm.

Well, one of the drawback of this control algorithm is that we are giving a entire burden of the power drawn from supply for load or for the losses of compensator only through a PI controller. So, you may find little overshoot and undershoot under dynamic condition on the DC link. I mean like, if the parameters of the PI controller are not properly designed there is the chances that you may damage even your voltage source converter, I mean if properly controlled tune PI controller is not tuned also.

Some time we use the sliding mode controller. We does not have a overshoot undershoot, but that may have a 1 or 2 percent steady, 1 percent steady state error, but certainly you will not damage the devices in that case. [FL] that is about the typically first typically control algorithm for power factor correction.

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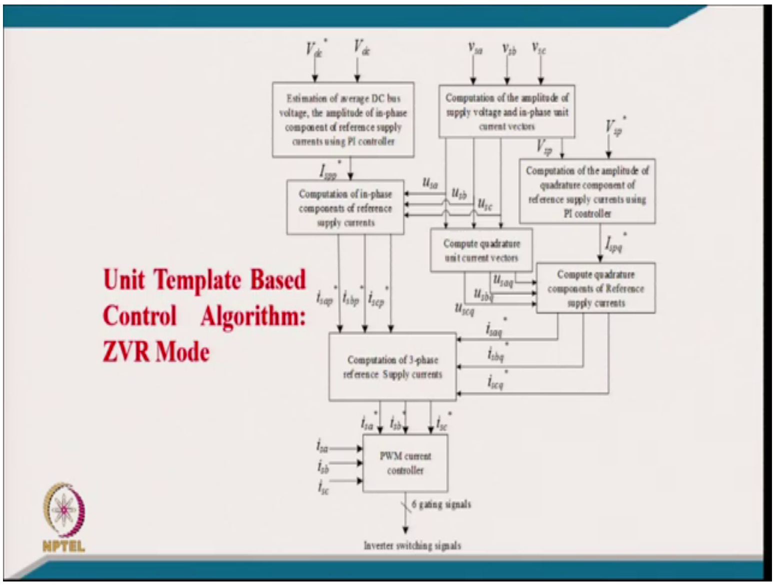

Now, modification of this of unit template control algorithm for zero voltage regulation, I mean we have here. What is the zero voltage regulation? In the sense now, we like to regulate the voltage at the load terminal equal to the supply voltage, I mean like. [FL] now we have to use the not only DC link voltage control.

DC link voltage control again we have to keep in the similar manner as we did in the previous case because otherwise your voltage source converter or inverter cannot run steady factory for current control. [FL] again the DC link voltage we have to have a block here, already I mean we have a reference DC link voltage and we have a this you can call it the your DC link voltage, sense DC link voltage after the low pass filter.

[FL] we estimate the DC link voltage and amplitude of in phase current of supply current by putting a PI controller which we discussed in the previous block and this becomes the amplitude of in phase component of current, ok. Because we are getting from, again from line voltage we are getting the phase voltage and from dividing the amplitude, I mean we are getting the phase template which you discuss in PI controller.

And this template along with this amplitude we get the active component of current which is in phase with the voltage. [FL] this is one component.

But you can understand for voltage regulation we have a another component because load voltage can be maintained constant or equivalent to the what value you require may be equal to supply voltage, when you really require a reactive component for. I mean you use the lot of compensator I mean distribution system like a capacitor panel for elevating or regulating the voltage.

Here also we have to put you can call it like, even if it is a like a normal case like inductive load or resistive load it means you have to put a little your capacitive current also to regulate the voltage to take care of the drop in the source impedance. Of course, if it is a load resist already inductive and voltage is typically going up then it may be of inductive current otherwise mostly say capacitive current.

[FL] we have here already the amplitude of supply voltage, sorry load voltage which we estimated at the point of common coupling and peak, we have already. And we take a reference of this which we may have already as a reference like a 415 volt, the peak of 415 into root 3 sorry root 2 or phase voltage we can take here because it is a amplitude of phase voltage. [FL] it is a 239 into root 2 that will be the peak for given way here typical example.

And then we have a I mean estimated voltage or the feedback here, [FL] we can calculate the amplitude of quadrature component keeping a reference supply current using again another PI controller. [FL] over the [FL] these are also DC quantity under the steady state condition. [FL] we can keep another PI controller. And this output we consider it again of PI controller the typical value of you can call it the quadrature amplitude of quadrature current.

It may be leading or it may be lagging, mostly it should be leading current amplitude, I mean from the supply voltage. And then, we have to what we have to do? We got already the amplitude, we have a phase voltage, [FL] by this transformation you can call it we have to compute the quadrature template because these current are the reactive current, [FL] we must have a template which are 90 degree leading than the voltage.

[FL] after getting this template we can get it another set of template which are at 90 degree leading than the voltage or from this template. We will discuss how we get the relation and multiplying this template with the amplitude, we will get a quadrature component of supply current.

As I have told you this amplitude if it is a positive it might be capacitive, if this amplitude is negative it may be inductive current, but it is multiplied and it go on changing like typically.

[FL] here what we have typically, now the quadrature instantaneous current we have a phase instantaneous current, we add together, I mean as a lubric sum and we have a total reference supply current for 0 voltage regulation. We have a feedback supply current, and we put a PWM current control which I have mentioned it can be hysteresis or run of PWM current control or it can be the PI controller with a carrier wave comparison or any other control.

There are plenty of current controller, when you find, you may find complete book on the current controller. And we get the 6 set signals for three-phase DSTATCOM 6 switching signal for 6 devices of three-phase voltage source converter like I mean. So, this is for the modification for 0 voltage regulation mode of this here DSTATCOM.

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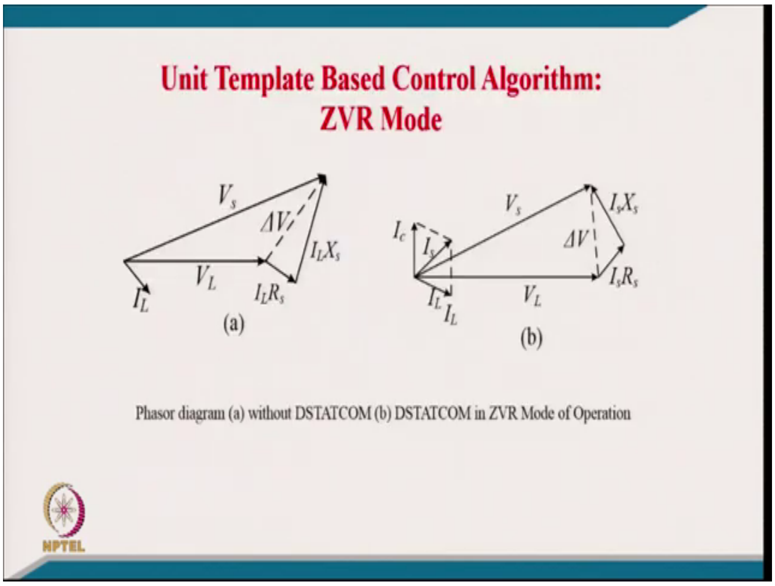

Now, coming to just to explain what is the typical difference in the two cases [FL]. I mean DSTATCOM in ZVR mode, I mean without DSTATCOM or with DSTATCOM. [FL] this is a case when we have a normally the case, I mean of typical example that we have a load voltage, we have a load current, and we have a resistance drop of feeder impedance which we discussed in earlier many examples and then we have a reactance drop which is 90 degree from the load current and then next comes the supply current.

[FL] supply current in most of the cases because if source impedance is now inductive in nature, and load is also like a lagging power factor. Why? Your source impedance is inductive nature because you might have already the transformer is in the distribution system. [FL] then this will be like a inductive nature and you will have a typically the source voltage higher than the or the supply voltage higher than the load voltage. This is the actual case.

But if you want to regulate the voltage which we discussed earlier also from the phasor, you have a load voltage. I mean in that case you have to add some, if it is a load is lagging power factor load you have to add a capacitive current not only for power factor correction. But you have to lead in more and then the current should be leading than the your supply voltage, [FL] slightly leading here if you see it.

[FL] if this is the leading current of the supply then the resistance drop will be also in phase with the supply current and then at 90 degree will be the your reactive drop. And then this voltage and this voltage should be on the same you can call it same arc here, so that the magnitude of V L is equal to V s.

[FL] this is practically possible, but you can understand here we have to provide little more leading current, not only power factor, but little more leading to take care of the this drop also, then only we will get a zero voltage regulation. I mean that is the basic concept here and we already explained the control in that previous slide like.

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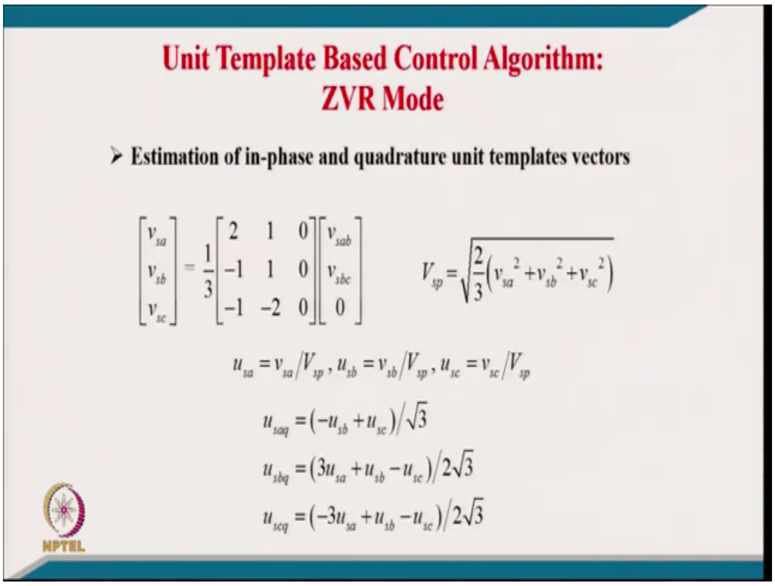

And the algorithm, I mean in the same, from line sense voltage we calculate the phase voltage and from phase voltage I mean we get typically the amplitude of phase voltage, and from this as we discussed earlier we get the template in phase with the supply voltage. And from these templates, phase template by this transformation we get the quadrature template which are 90 degree leading. I mean u saq is the 90 degree leading from u sa.

I mean like because we already calculated this template, [FL] these 3 template will be 90 degree leading. This will be 90 degree leading from u sa, this will leading 90 degree from u sb and this u sq will be leading then 90 degree from u sc like I mean or so.

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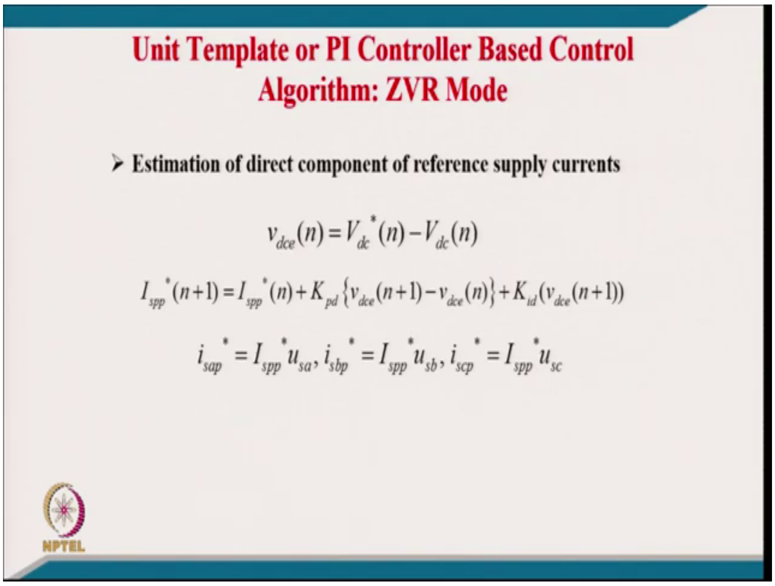

And coming to again, I mean for direct axis of supply current again we are using a PI controller on DC link of voltage source converter is a operating as a DSTATCOM. And we have a reference voltage, and minus the feedback voltage, of course, after the low pass filter and then we have a PI controller. And this we get the in phase component similar to like what we discussed already under as unity power factor operation mode. [FL] this is it. We can call it direct component or in phase component of reference supply current.

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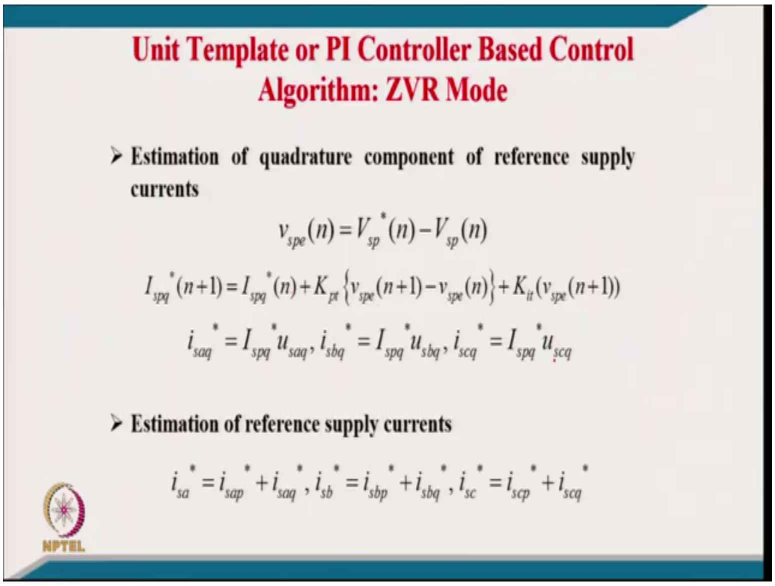

Then we have a estimation of quadrature component. For getting a quadrature component we take a amplitude of your PCC voltage, reference what we want and this is a feedback amplitude of the your reference voltage which we calculated in the previous slide here already like I mean or so. [FL] we got already here. [FL] this is the voltage error and we use again PI controller for quadrature component, [FL] this is the amplitude of quadrature component which you are getting from PI controller.

Well, and then this is the quadrature component of current. And we get the sum of phase current plus quadrature current, all are instantaneous quantity, [FL] we get a reference. You can call it like a typically a reference a phase current, b phase current of supply and c phase. This we expect if it is a leading power factor load and this should be a little slightly leading current as because this will be a leading current, 90 degree leading the second component of that like.

And typically; [FL] that is in this case one important aspect is there, I mean I will just mention here. Sometime, I as I have mentioning earlier that may be in phase component for DC link voltage control, we normally for this controller we keep showing here PI controller for both, but here we can use the sliding mode controller.

There may be a slim small steady state error in DC link voltage, but that is your internal structure of the DSTATCOM. But these controllers should be PI controller because PI control have a zero steady state error under steady state and you will like to regulate the load voltage at the point of common coupling because it is fed to the load.

[FL] consumer will see this voltage to be regulated. But the consumer will not be able to see within the I mean your DSTATCOM whether the DC link voltage is slightly more or less. But you have to operate the DSTATCOM very satisfactorily. [FL] this completes your typical unit template based controller algorithm. The first control algorithm for power factor correction and voltage regulation like.

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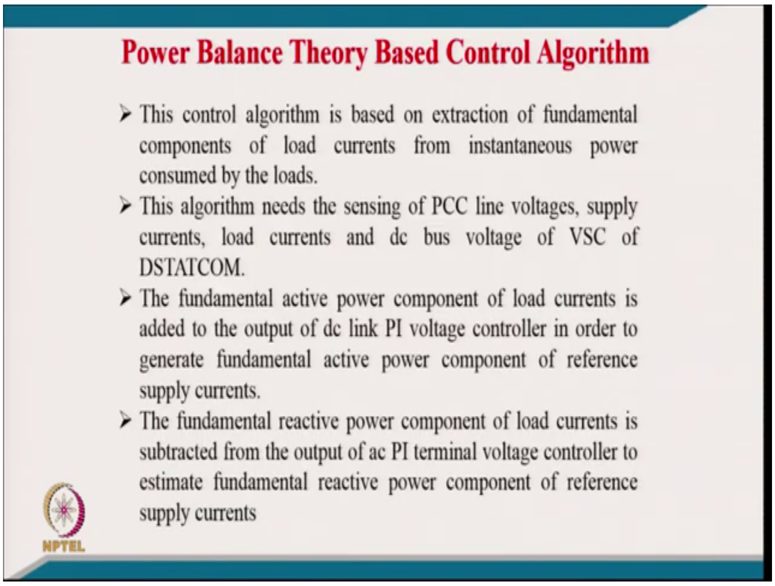

Now, we will go to second control algorithm I mean this is why which we call it the power balance theory based control algorithm, which itself my I developed in 1996 typically. And you will find certainly some literature related to that. [FL] this control algorithm is based on a very simple concept of, [FL] we will discuss that what is that concept is.

This control algorithm is based on extraction of fundamental component of load current from instantaneous power consumed by the load or load consumed that instantaneous, I mean your active power. And this algorithm needs the sensing of PCC line voltage, supply, current load current and dc link voltage of VSC. In previous algorithm of unit template, of course, we are not sensing the load current, but here we require this is the sensing of the load current.

The fundamental active power component of load current is added to the output of dc link voltage control in order to generate the fundamental active power component of reference supply current. And fundamental reactive component of load current is subtracted from the ac PI controller to estimate the fundamental reactive component similar to as what we discussed previously here.

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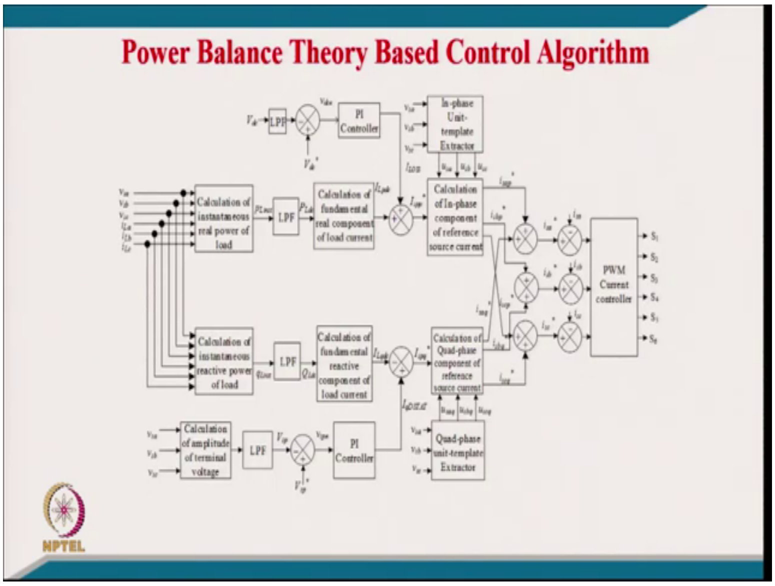

[FL] what I mean here we are getting a load? Load active and reactive power and that we are taking into control because the reason being here, I mean we will discuss with this here, because the load is consuming typically you can call it like a major amount of active power and compensator hardly may be having a 2, 3 percent losses. [FL] this control algorithm certainly will reduce the burden on the both the typically on the PI controller, both the PI controller.

I mean for voltage regulation as well as the your typically for power factor correction. [FL] here of course, we can discuss here what we are sensing here, we are sensing the three-phase voltage maybe line voltage, I mean because phase voltage in 3 wire system is not available and then we have a three-phase load current estimation, ok. [FL] from this three-phase voltage and three-phase if we are sensing the phase line voltage we can estimate the phase voltage from that.

[FL] from phase voltage and phase load current, we can calculate the instantaneous real, instantaneous real power here. What we can do?

We calculate it the instantaneous power as a just multiplication of the v sa, i La, v sb, i sb, v sc, i sc, we will just discuss in the expression and this will certainly will have a ripple of this PL because it is a ac power, [FL] you will if it is kind of like a unbalancing either in load, either in load current or in voltage you will find this is certainly not only the constant quantity, but you will have a some ripple over it, ok.

Then, certainly we have to use the low pass filter to get a active power, active component of power from this load current. [FL] this is a load active power component of current. And using a relation from power we convert into current form the amplitude of the voltage we will discuss of course, in the equation. [FL] we got a one component of load current.

And we got a another; this is the active power required for the load from the supply. And we have another again the PI controller of the here what we discussed earlier also, I mean we have a reference voltage and we have a feedback voltage after the of the DC link of the your voltage source converter operating as a DSTATCOM and using a low pass filter we get DC component and we use the PI controller. [FL] this represents the loss component of DSTATCOM.

Whatever the losses in DSTATCOM whether it is interfacing inductor ripple filter, and devices and dielectric loss in the capacitor of the DC link. [FL] this is the loss and this is the active power of the load, this is the total active power drawn from the supply for this system. I mean you can call it like on it. And certainly from supply voltage we calculate the template in phase and this amplitude is multiplied with the template, [FL] we get the active component of current or in phase component of the typically of supply current like I mean.

[FL] similarly, this is for active phase component of current. And similarly from this your supply current, supply voltage, and load current we get the reactive power, we will talk about from the this reactive power calculation is also a straightforward formula. And then again here also if it is a unbalance is there either in voltage or current in both you will get a ripple, [FL] we have to use low pass filter. And with the low pass filter we get the fundamental reactive power of the load with load is consuming.

And from this of course, with the amplitude of the voltage we are able to get amplitude of the reactive current. And of course, from these voltage we are getting amplitude. And amplitude also we if it is a unbalance we use the low pass filter, [FL] we have a reference amplitude of voltage. We have a typically feedback voltage and we use the PI controller to regulate the voltage, [FL] we get the quadrature axis of component.

Well, this is to be provided I mean like, typically, by the DSTATCOM, ok. And DSTATCOM, this component is provided locally to the load and this minus this is flowing into the supply system because we are finding the supply, typically the supply reference current, [FL] it means the DSTATCOM will supply this locally to the load and remaining the difference of these two have to flow into the supply for regulating the voltage at the point of coupling. For some leading current I mean have to flow into the supply feeder impedance also otherwise you will not get the zero voltage regulation.

[FL] you have a amplitude of the leading current flowing into the supply or reactive current flowing into the supply multiplied the template which are at quadrature, [FL] you will get a quadrature current typically with the quadrature with the supply voltage I mean. And adding the phase component and quadrature component, we get the total supply current, we sense the supply current and we have a PWM current controller formatting this.

[FL], well, this can be big. Why I have integrated only for voltage regulation here? If you make typically this as a 0, the control scheme may automatically modified for power factor correction. Just make this 0, [FL] control is for power factor correction, but if you allow this it is for voltage regulation like or so.

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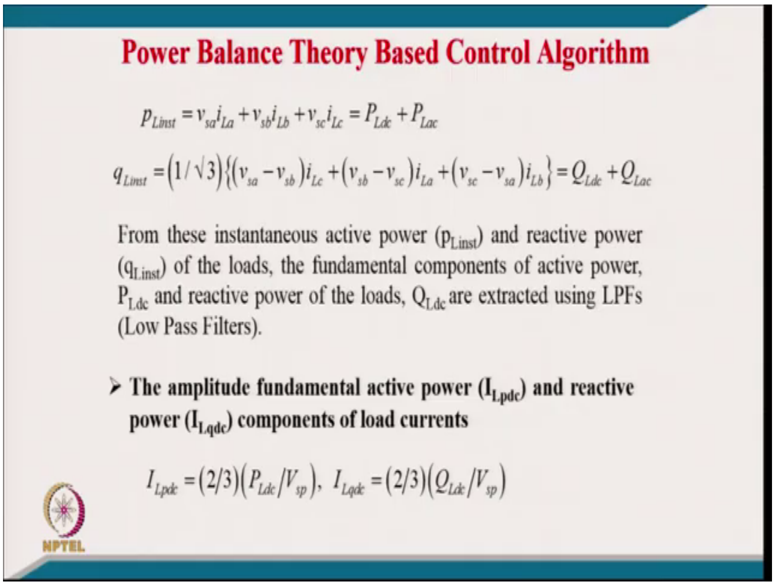

Well, these are the now typically the expression that power balance theory based control algorithm, [FL] we calculate instantaneous power from these expression v sa i La plus v sb i Lb, v sc i sb. [FL] it has a ac component dc component and ac component. By filter, low pass filter which I explained we get only dc component which we require for there. And from this relation you get the your instantaneous reactive power, instantaneous reactive power, the reference of two voltage with the a i Lc current and similarly for a typically from b and c phase voltage and i phase a cross kind of coupling.

And here you have it again two dc component which is a active, which is reactive power fundamental reactive power fed to the load and this is the you can call it the ac component of it. [FL] again we use low pass filter to get this, ok which require already we discussed in the block how we have.

[FL] from these instantaneous active power and reactive power of the load the fundamental active power, this dc component and fundamental reactive power typically these component are extracted using low pass filters, I mean which is shown in the block diagram.

[FL] the amplitude of fundamental active power component and reactive power current can be calculated from equivalent to this load is here, 2 by 3 because it is a power [FL] divide by amplitude the voltage for three-phase, [FL] we have to get equivalent for power phase.

[FL] we get the amplitude of your active component amplitude of reactive component corresponding to the load, where the load requirement, and this is have to come from supply, and this have to come from the your DSTATCOM like.

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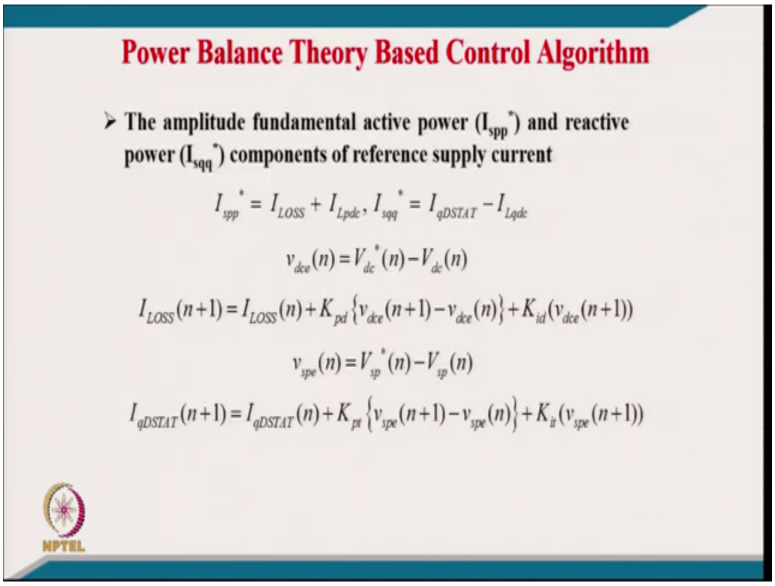

And now, we can find out the amplitude of supply current of active power. [FL] active power, what it consists? Loss plus the active power we entire draw from the supply only, loss of compensator plus the active power for the load. But for reactive power core compensator, I mean load it feeds locally that is why the minus [FL] this difference comes flow into the supply, ok, only the different.

I mean DSTATCOM locally filled the load only difference come from supply, and then typically we put the again the dc link voltage controller for getting this loss component here which are using here. Another PI controller getting this volt for voltage regulation this component of current which is used here. And these already we got from the load. [FL] we get the amplitude of your supply current for phase component and quadrature component.

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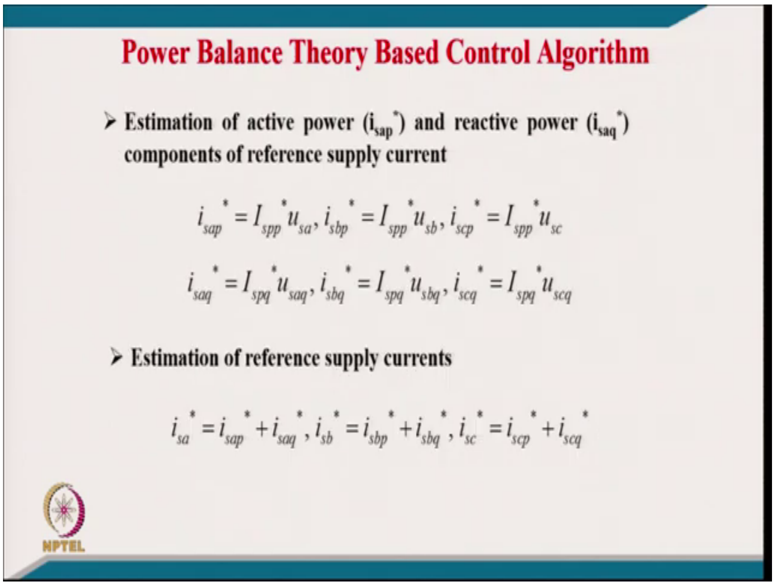

And now coming to these two relation for estimating the instantaneous reference supply current for phase component. We already get amplitude, multiplied the phase for a phase, b phase, c phase, similarly for quadrature component and by adding these two we get the supply reference current.

And sensing the supply current we can use the current controller virtually for typically for maintaining the, typically for 0 voltage regulation. But if you maintain in this case typically this only this element 0 then you can rely the for unity power factor operation like I mean or so. So, that is about this control algorithm.

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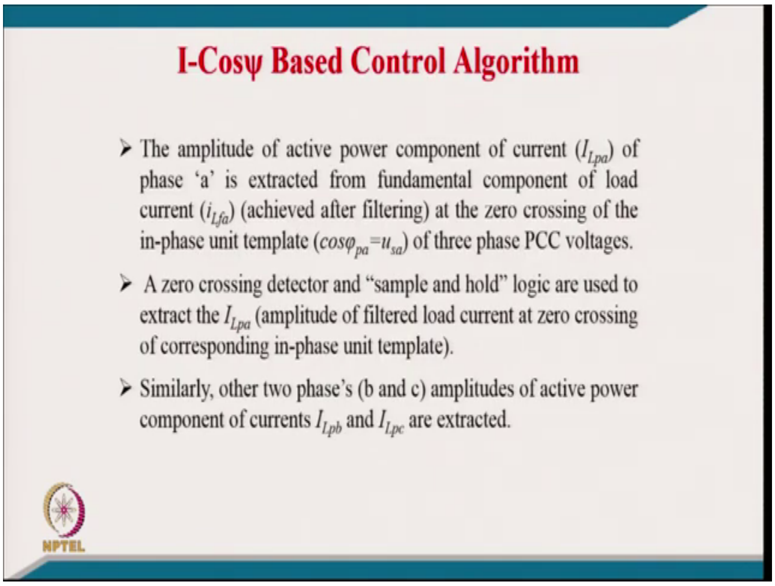

Coming to another control algorithm, I mean I-Cos phi based control algorithm that is a interesting algorithm like I mean for DSTATCOM. [FL] amplitude of it the active power component of current for phase a is extracted for fundamental of load current achieve after filtering at zero crossing of the in phase zero template of the three-phase voltage.

And at zero crossing detector "sampled and hold" logic are used to extract the amplitude of filter load current or at zero crossing of corresponding in phase unit template. [FL] similarly, for other two-phases, amplitude of active component of current are extracted like I mean.

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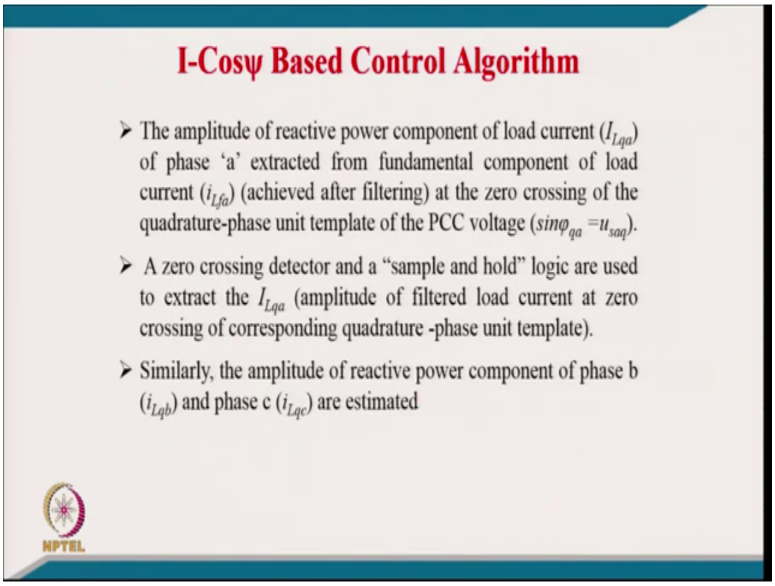

[FL] you can call it the amplitude of reactive component of current of phase a extracted from fundamental load current after filtering at zero crossing of your quadrature component here. [FL] a zero crossing detector and a sample and hold logic are used to extract the i Laq that is amplitude of filter load current at zero crossing which is the quadrature at quadrature component. And similarly, amplitude of reactive component at phase at b and c is calculated.

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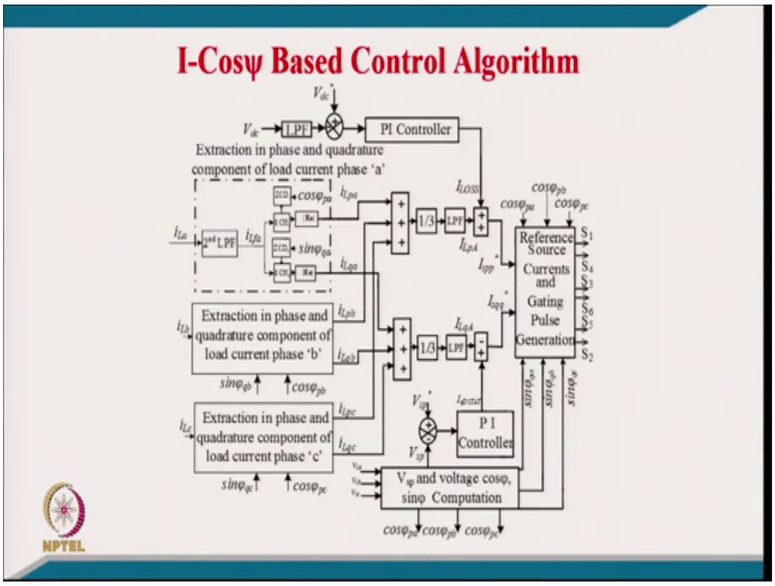

[FL] here we knew, not only we use the logic and probably the zero crossing of the voltage also. [FL] you can say DC link voltage control is the similar to as in previous two algorithm. We take a reference DC link voltage for DSTATCOM or voltage source converter, and we have a feedback voltage, we use the low pass filter, and we use the typically here the PI controller like.

[FL] we I mean considering the 3 load current how we are extracting the active component reactive component, I mean we are using maybe current maybe distorted or maybe fundamental only, [FL] we take by the second low pass filter fundamental component.

And then we use here, I mean the template at zero crossing we take real component, and another template with the zero crossing, I mean like we take that reactive component. [FL] these two reactive; and same thing we repeat for all three-phases. [FL] we got the active component all three-phases reactive component and this may be unbalanced, your load might be unbalanced.

[FL] then, we have to take average of this because the only active component I mean these are typically a fixed quantity for a steady state system divide by 3, we actually we are providing load balancing and we are giving low pass filter, [FL] we are getting active component of current.

This have to come from supply. This is also from supply for loss, [FL] we get the amplitude of your active current component of the supply current. And here we get of course, the reality component of load current again for load balancing we divide 3 and we use low pass filter where the amplitude of the quadrature component of the load and well DSTATCOM have to provide this.

Part of this have to fed locally to the load, [FL] remaining comes from feed flow into the supply. And multiplying this template with the quadrature here and phase with this, we get the typically the total reference supply current I mean like added which we have given equation, and we get the switching I mean by putting the sense current from there like I mean.

So, that is the way. And certainly from this block I mean we can get a unit template. These are the virtually called the all these are the unit template which we are otherwise estimating in other two control algorithm like I mean or so.

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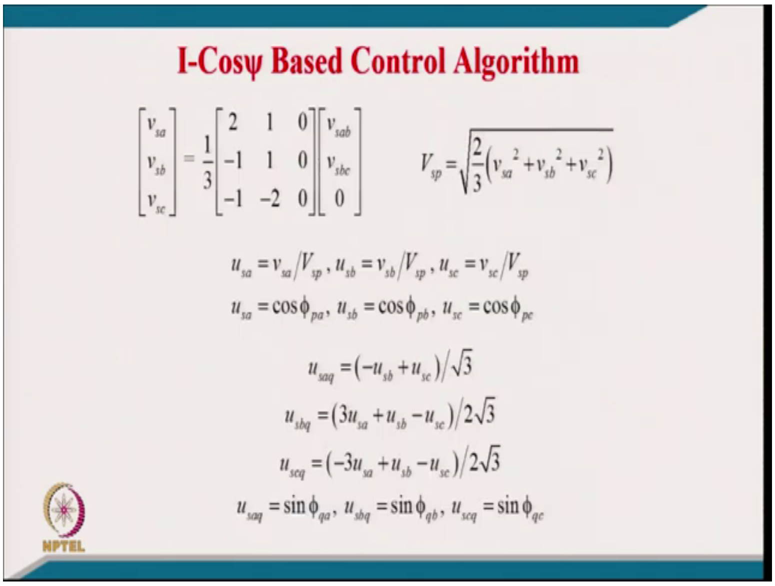

Well, the basic expression, I mean here it is that from sense line voltage, we get the phase voltage, and from we get the amplitude from phase voltage, we get the in phase template. And in phase template only we consider this you can call it typically required for sample and hold, we get the quadrature template from a phase template, and we consider the for this for sample and hold like I mean or so.

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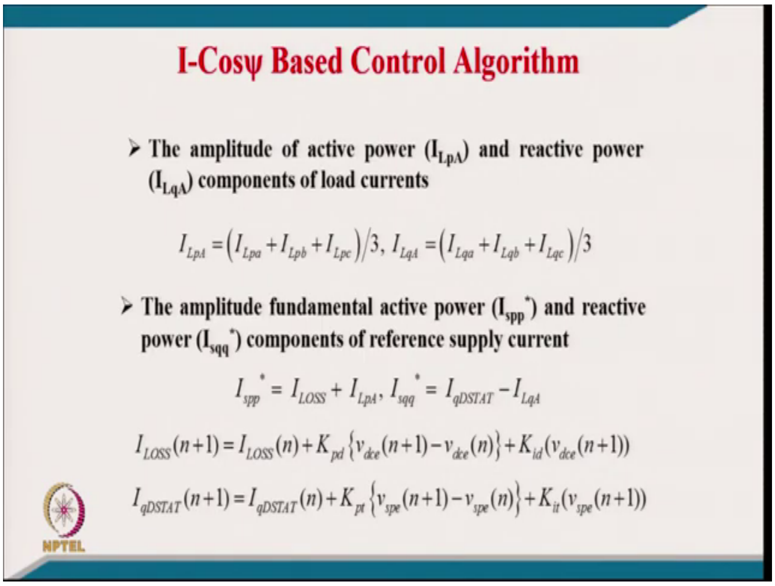

And the amplitude of active component and reactive current component we can get for the load by for load balancing divide 3 because all 3 may be un equal, [FL] this for load balancing. And then for active component we add with the loss that is PI controller output.

Here we subtract because this has part of reactive power, generated by the DSTATCOM have to fed load, remaining only have to flow into the supply, [FL] we got the amplitude of active component, the reactive component, I mean and these are the two PI controller equation for getting the two loss and second for typically for voltage regulation.

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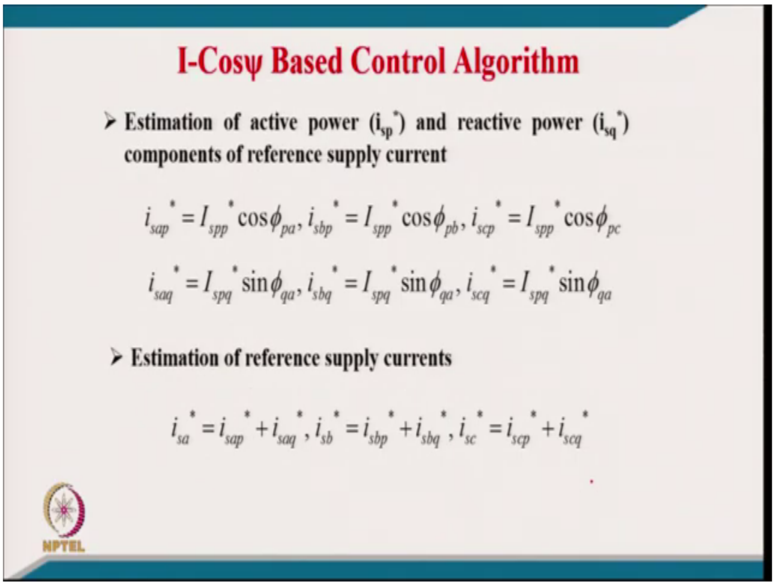

And then, we get the amplitude for phase component, multiply the template and quadrature component multiply the template and we get the total reference supply current. I mean here, for a phase, b phase, and c phase, and sensing the supply current you can put a current controller for getting the your switches of the voltage source converter is used as DSTATCOM like I mean or so.

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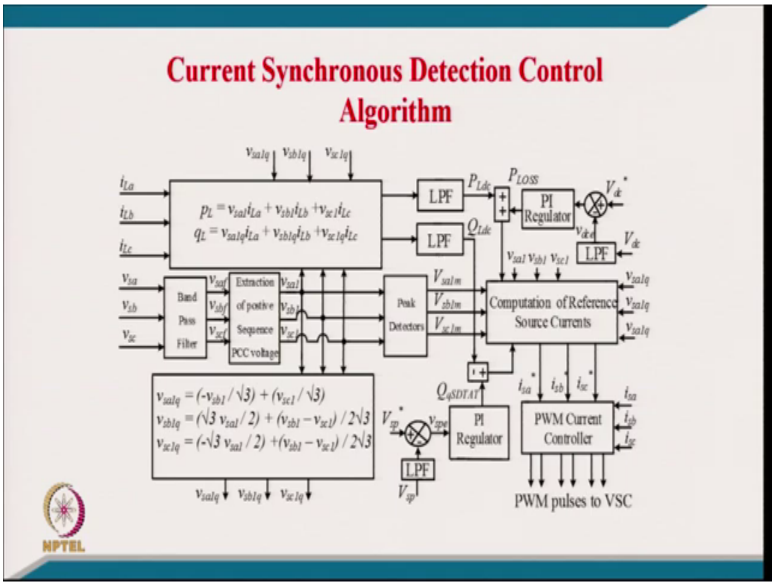

Well, this is the second control algorithm. Now, we come to this sorry I-Cos third control. This is another control algorithm which called current synchronous detection control algorithm. Virtually, it came from concept from communication system, people have use it. It is also very straightforward, similar. There is, have a little similarity in most of the control algorithm, once you understand free then you will go on understanding others [FL].

Here again we have a typically, I mean you can call it the voltage which are in quadrature, we have a load current, [FL] we can find out the I mean instantaneous power load power, instantaneous reactive power. After filtering low pass filtering we get the DC component of fundamental active power of the load, fundamental reactive power of the load and from this voltage of course, we can get a band pass filter the fundamental voltage, we can take a positive sequence of it and we can calculate the amplitude of from it.

And from this of course, we require for calculating. [FL] we have a active power. We have again DC link voltage controller similar to previous algorithm. We take a DC link voltage feedback and use the low pass filter to get only DC part of it, and protecting from reference we get [FL].

After PI controller the loss component of power this is load power, [FL] total power here comes, similarly reactive power we get a from voltage regulation. I mean we have a reference voltage, we have a I mean estimated peak of voltage and from this we get the error and we use the PI controller, [FL] this equivalent DSTATCOM minus the load that is the reactive power have to come from the tip have to flow in the supply.

[FL] we have a active power, we have reactive power, I mean be to be taken from the supply system and we have a positive sequence voltage in phase and quadrature and we get the typically the supply current here for this current synchronous reduction method. And we have a sense supply current, we give the gating signal. I mean again here also if we make this 0, it will be modified for power factor current, unity power factor operation and if it is there then it will be for 0 voltage regulation like I mean or so.

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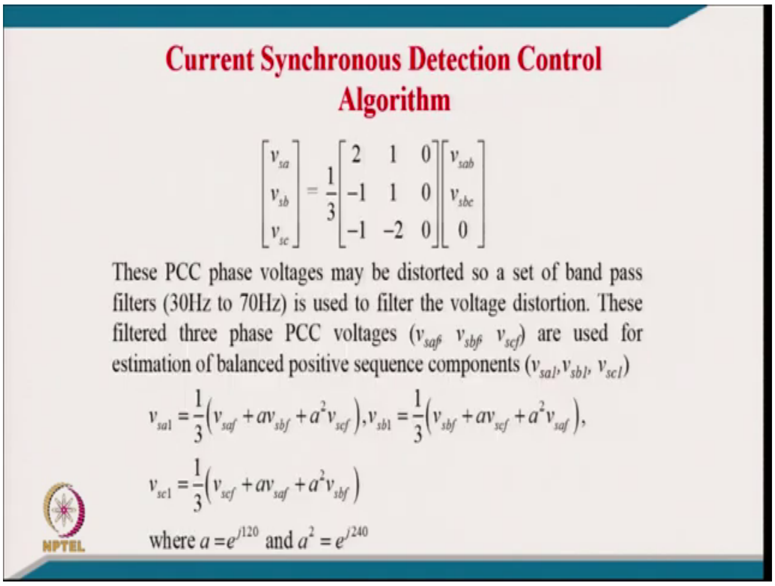

And these are the typical expression that we have from line voltage, we are getting the phase voltage similar to what we discussed in other control algorithm. And these PCC voltage may be distorted to a band pass filter I mean like have to be used to filter out the voltage distortion and these filter three-phase voltage is I mean fundamental voltage are used for estimation of positive sequence voltage.

This is the positive sequence voltage which I mentioning, I mean because in India we have even an unbalanced voltage, [FL] we can get positive sequence voltage which are balance voltage with this operator instantaneously.

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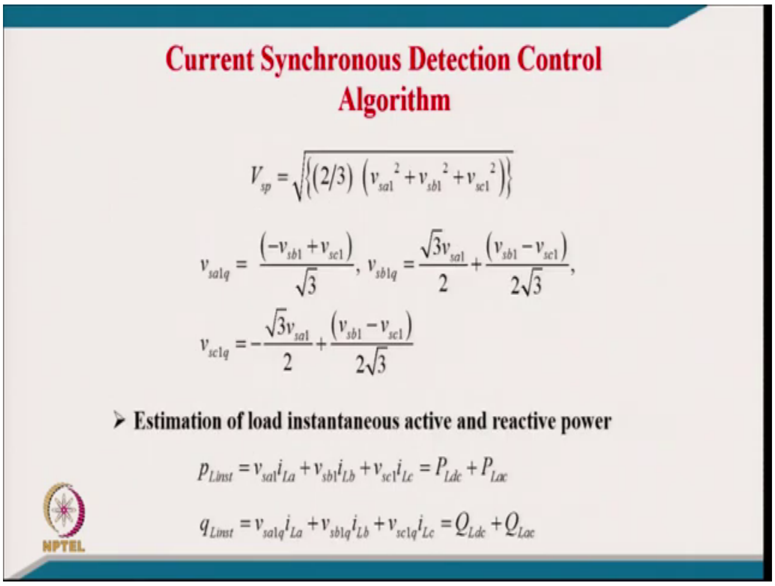

And then we can get the from phase voltage positive sequence voltage, we can get a amplitude of the voltage, and these are the typically the quadrature voltage. 90 degree away from the positive sequence voltage, and from this we can get a load instantaneous power and load reactive power, and after filtering we get the fundamental reactive power that is dc component and for quadrature, it typically even the fundamental reactive power of the load.

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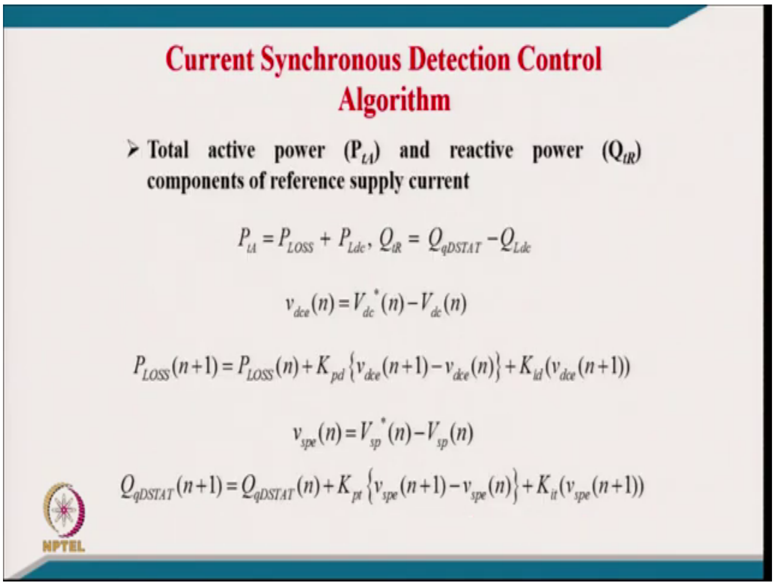

Then, we can get the total active power that is the loss means from the compensator using PI control over the dc link voltage. And the load active power fundamental active power which we have taken after low pass filter. Similarly, reactive power which have to flow from the into the supply system.

[FL] after the DSTATCOM have to feed some active reactive power minus the load active power which is we got the DSTATCOM reactive power, we get this both two power component and then we get from this power, active power, we are able to get active component of current from these voltage.

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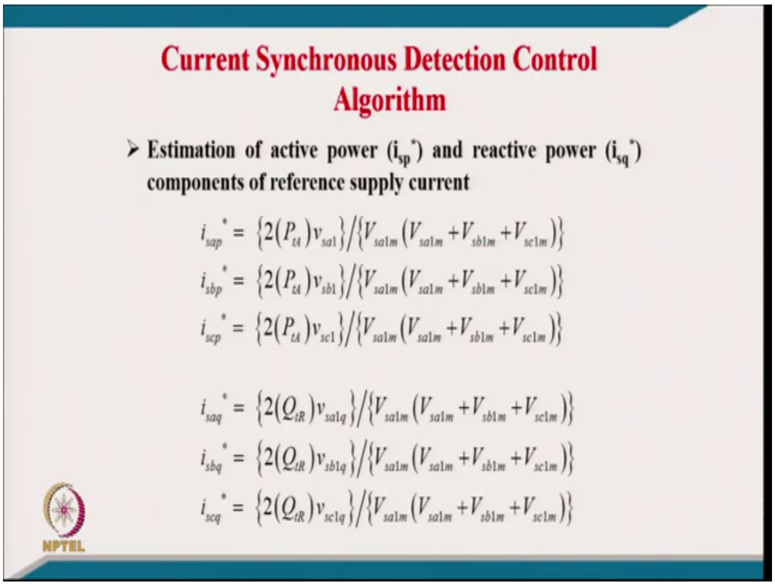

And from reactive component from this reactive power which we got it from using these voltage.

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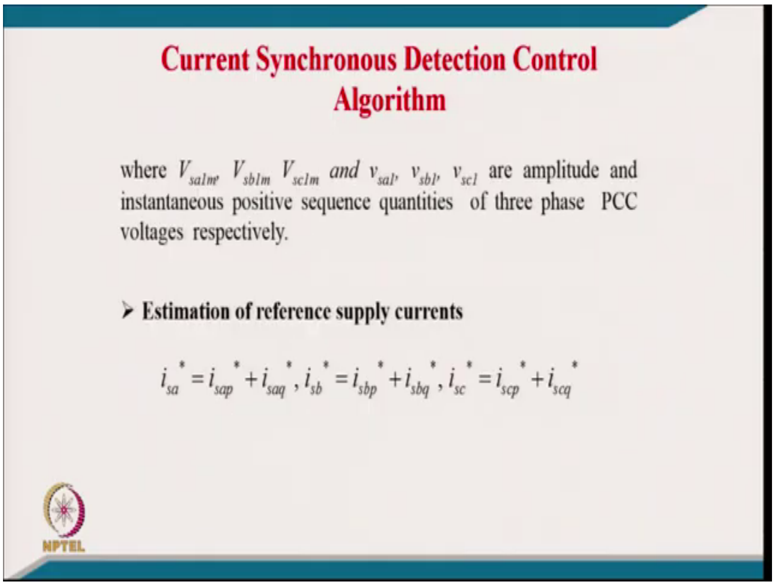

And then we can add these two component typically for active and reactive for all three-phases of grid current, and we can get typically the current controller in the same manner for getting a voltage regulation. But if you want typically only unity I mean power factor operation then you can keep this Q tR 0.

[FL] these 3 current will be 0. You will be having for power factor correction only this operating this DSTATCOM that is how you can modify the control algorithm for power factor correction. This is for typically for voltage regulation to take care of both the compensation into account here like.

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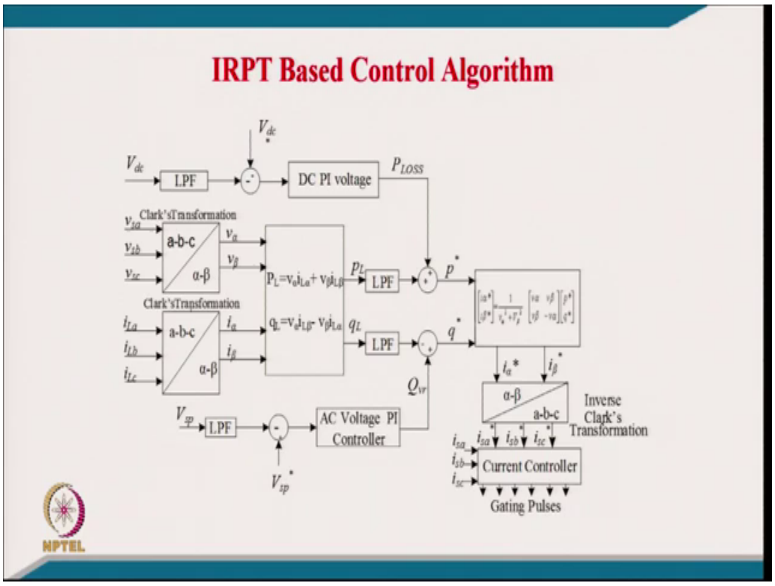

Well, coming to another control algorithm instantaneous reactive power theory based control algorithm, this is a, I mean the control algorithm developed by Japanese in around as old as maybe 1983, typically for these compensators, I mean like. And the basic concept of this is very simple using like Clark transformation, I mean like. [FL] what we do it here again, I mean a DC link voltage control of course, for operation of DSTATCOM again it is here we have a reference DC link voltage.

We have a for self-supporting DC bus, we have a feedback voltage and we use the low pass filter getting a DC component, and we put the PI controller this again we consider the loss component have to be drawn from supply system to meet the losses of the DSTATCOM including whether it is a loss into the interfacing inductor, whether it is loss in the ripple filter, loss in the your switches or loss in the dielectric capacitors, dielectric loss in the capacitor of DC link, [FL] that is have to come from supply.

Now, what we do it? I mean we have a again the sense PCC voltage, sense load current, we use the Clark transformation for a b 2 to alpha. Clark transformation in general is from any number of phases you can convert equivalent to two-phase which are at 90 degree. Here since we have a three-phase, [FL] we can convert three-phase to two-phase and we get in alpha-beta voltage.

And similarly, from load current we get the typically alpha-beta components of this. And from using this relation we get the instantaneous power, load power and instantaneous reactive power and which again we use the low pass filter to get the only DC component which is fundamental active power and fundamental reactive power of the load.

[FL] again we add this active power of load along with the loss of DSTATCOM, this active power have to drawn from supply. [FL] this is the I mean the active power drawn from the supply. And similarly, we have again the voltage regulation here, [FL] we have a reference amplitude of the voltage typically of have to be maintained at the point of common coupling across the load and we have again estimated peak and we use a low pass filter because if there are ripple.

And then, we use the again PI controller voltage control controller though this is the reactive power to be generated by DSTATCOM. Part of load reactive power I had to be supply here locally to the load and remaining reactive power have to be feed to into the grid that is the fundamental reactive power have to feed to integrate.

[FL] once we have a PQ, I mean reference from this inverse Clark transformation virtually of power we have a p and q reference, [FL] we are able to get alpha-beta current of the typical reference current for this.

And from this again inverse Clark transformation from alpha-beta to abc, we are able to get a reference. You can call it the reference grid current, we have a sense grid current and putting current control we are able to calculate typically you can call it like a current control and operation of DSTATCOM.

[FL] again for typically for unity power factor you can keep it 0, [FL] you will get these all current in phase with the supply voltage, [FL] that will be a power factor correction mode. Otherwise this is algorithm is again for generalized one as a for voltage regulation like I mean or so.

Here we put a indirect current control, but if you want to put a direct current control these p and q, I mean the q's will be of the your you can call it the total q if power factor correction there total q, virtually the total load q because it is to be compensated by load and p's will be the loss with typically I mean like only ac component of typically of this.

Because the ac component only have to supply form from DSTATCOM the ripple there, [FL] it should be a only the this and then this component because that also have to flow into the DSTATCOM.

[FL] virtually you can call it like the Japanese Akagi group and their book you will find this consist, p consist of loss component and ac component of this, [FL] this P L minus this have to be and plus this have to be this p star and q star certainly have to be total because that have to be generated by compensated that is the difference in direct current controller and indirect current control.

[FL] that you should not get confused if you look into the literature. We are taking I mean typically indirect current control means control on the grid current like or so.

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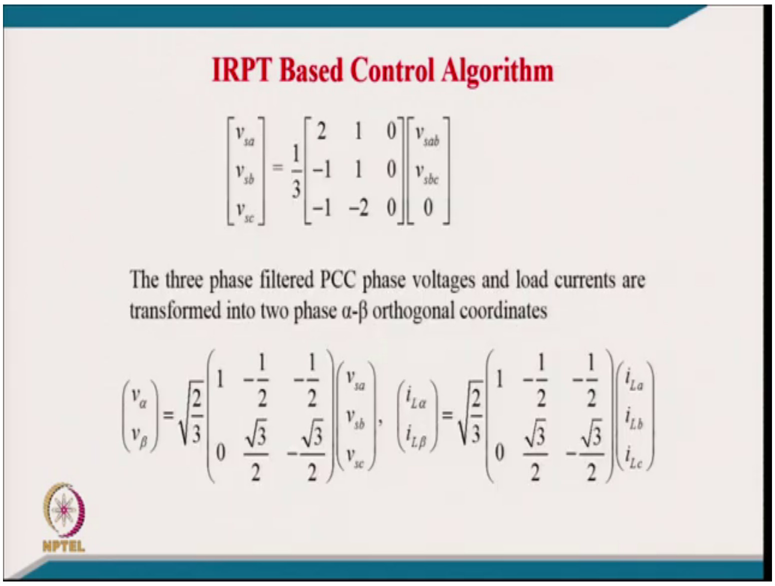

And these are the typical expression from line voltage. We are getting the mathematical proof, typically the supply phase PCC voltage phase voltage, and then these PCC voltage filter PCC and load current are transformed into two-phase transformation from v a, v sa, v sb, we convert into Clark transformation into alpha-beta, similarly load current we transform to alpha-beta.

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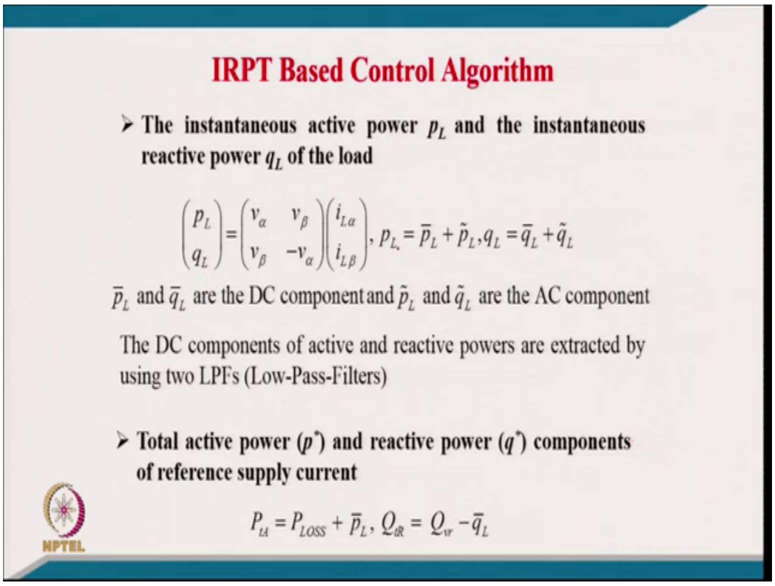

And then, we calculate the p L and q L from these two relation that is the total power DC component and AC component, DC component, AC component, and using loss component we take a DC component which is only the typically the fundamental component of reactive power, active power, a reactive power and reactive power of the load. [FL] p L and q L are the DC component.

And the p star and the p a c and q a c q L a c are the AC component of the load and DC component of active and reactive power are extracted from the two low pass filter.

And we get the total active power drawn from the supply, have to flow from the supply, loss component and the load active component which have to come from supply and in supply the DSTATCOM minus the, I mean the fundamental component of typically have to be selected which have to be supplied total from here, [FL] only supply we must have only fundamental component of this like.

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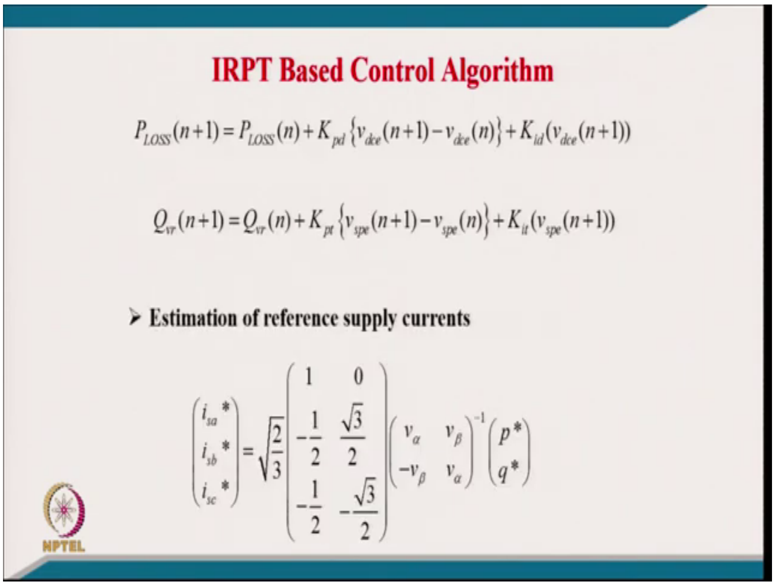

[FL] that give us the power and from of course, the active and reactive power I mean PI controller for DC link voltage control and voltage regulation are there. And once we know those p and q, form this I mean relation we are able to get the reference supply current typically from these two relation like I mean.

[FL] these are reference supply current and we can have a sense supply current, and we put the typically the current controller on current to get the DSTATCOM operation like. And of course, you can understand if you want unity power factor operation you can keep this as a 0, only p will be there, [FL] that will be unity power factor operation of your DSTATCOM like I mean or so.

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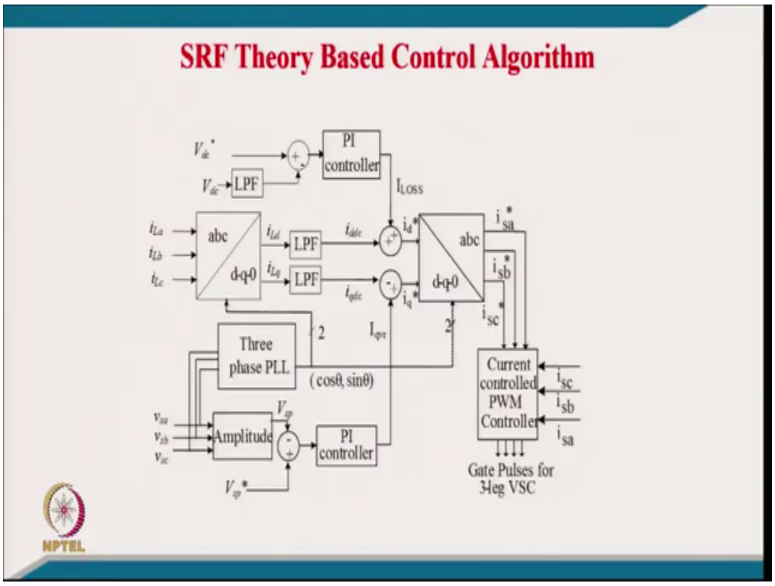

Well, we have a another control algorithm which is very famous algorithms synchronous reference frame theory, based control algorithm.

This is DQ theory which are used in electrical machines analysis, as well as use in the vector control of the motor drive AC motor drive, right. These are the same algorithm which is used first time by Wisconsin group, I mean and these reported widely and huge for lot of system like including the typically not only DSTATCOM, like active filter as well as solar inverter, [FL] plenty of places these are used.

[FL] here also of course, we use the again the self-serving DC bus. Again, we have a DC reference DC link voltage, we have a feedback voltage of the DC link of voltage source convertor operating as a DSTATCOM and we use low pass filter, [FL] put a PI controller we got a loss component.

And here what we are converting the load current, I mean we are transforming from abc instantaneous quantity into DQ transformation, [FL] well, we get a i Ld, i Lq. And these two current virtually active component reactive component, I mean because load may be unbalanced or typically like maybe distorted [FL] you will get a ripple for DC. [FL] you use the low pass filter then you get a fundamental active component of current and fundamental reactive component current of the load.

And this have to come from supply, loss also have to come from supply, this you get the total current typically, I mean total active component of current drawn from the supply. And similarly, we have we are sensing the voltage and filtering the voltage phase voltage and from PLL we are getting the cos theta, sin theta, which is used in this transformation from abc to DQ.

And same be used for inverse Park transformation, and we get the amplitude and we control the voltage again here PI controller, [FL] this is to be generated by DSTATCOM, minus the reactive power required by the load which it meet locally the difference will flow into the supply.

And we have i d, i q of the supply and then we use the DQ to abc transformation, [FL] we get the three-phase reference current on the grid side and we sense the grid current and we have a current controller to generate the gating signal for three-phase voltage source converter operating the DSTATCOM [FL] that is a block of synchronous reference from theory. It is also called DQ theory.

Typically, the here if you are not if you are using a power factor correction the I mean other than cos theta, sin theta voltage are distorted that is not going to affect your because this is used on the current base. And we do not use the power here. I mean we are not using the typically the voltage in this case also. [FL] that is a typically the benefit of the, I mean like.

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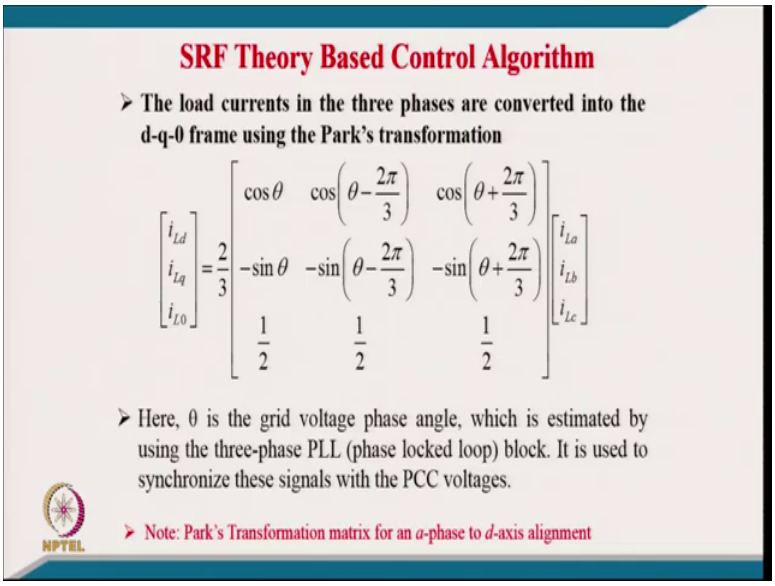

[FL] the basic equation for three-phase load current in three-phase are converted to DQ using a Park transformation, and we have a load current which we transformed by this Park transformation. This is a Park transformation matrix where theta is nothing, but your we get from PLL or the voltage or you can use the template concept also what we already discussed in other control algorithm that also you can get the cos theta, sin theta, typically from there also.

And we get i Ld, i q 0 as becaus e it is a 3 wire system [FL] we do not have 0 sequence, [FL] we can use only i Ld, i Lq as you saw on the block and this is what we are getting this and Park transformation matric for f a to d q alignment.

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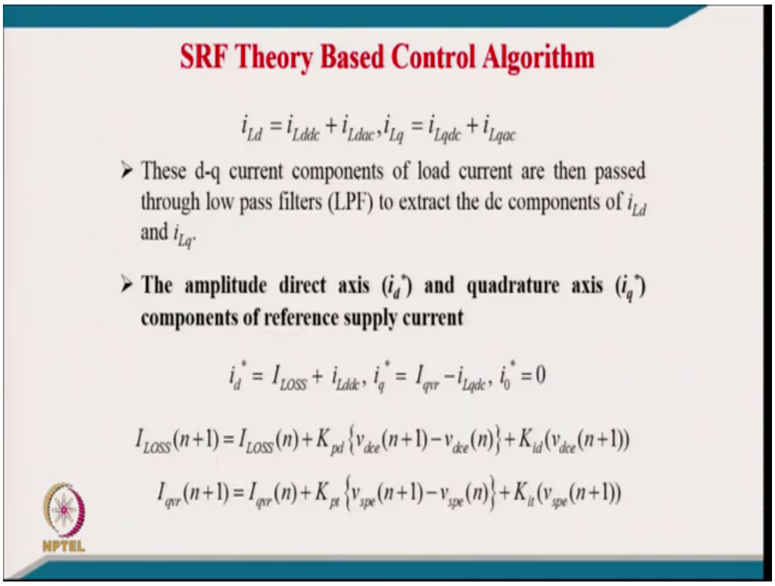

And you get a again AC; DC component and AC component, and DC, AC component active. You can call it reactive active power of the load, reactive component of load, and you can filter it by your low pass filter to get DC component of typically for active component on reactive component. And then, you have a typically the your DC component or active component loss plus the load, active component fundamental current.

And similarly, quadrature DSTATCOM minus the load its load have to fed locally and 0 sequence is 0, and use the PI control to regulate the DC link voltage and PI controller for regulating the thermal voltage, PCC voltage.

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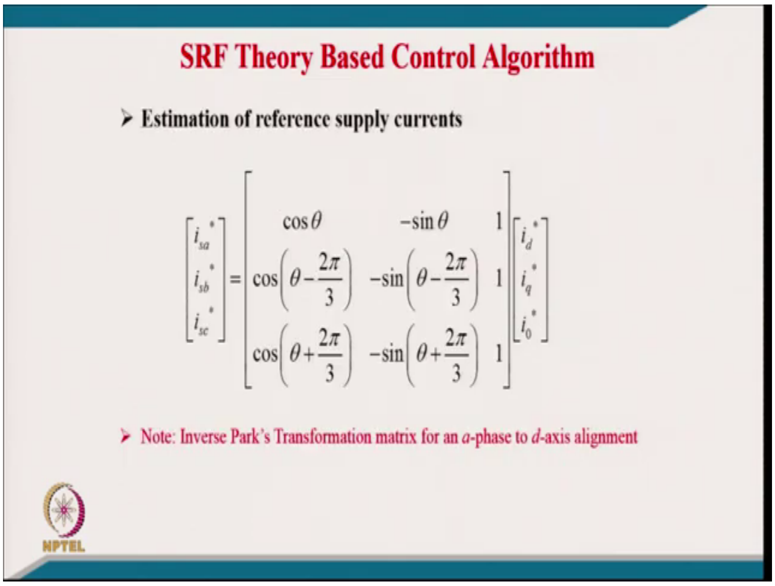

And once you know that I mean, this i d, i q, i 0 and you already have i d star you convert into the back to inverse Park transformation to get three-phase reference grid current. And we put a current controller on grid current to have a indirect current control for switching deriving the switching functions for the voltage source converter for operating as a DSTATCOM or so.

[FL] we discuss these 4 control algorithm, I mean typically starting from you know template theory, then we have gone to a another control algorithm we call it typically the power balance theory, then we discuss the a synchronous reduction theory. We have discussed the you can call it the IRPT instantaneous reactive power theory, and then the synchronous reference frame theory. [FL] we discuss virtually the 5 control algorithm. [FL] remaining algorithm we will discuss in the next class.

Thank you.