Flexible AC Transmission Systems (FACTS) Devices
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Lecture - 39
Interline Power Flow Controller (IPFC)-II

Welcome to our second lectures on Inter line Power Quality Conditioners, though on AC Flexible Transmission System we shall continue with us actually the operating principle of the IPFC. So, what we are discussed in our previous class that the in general at a selected operating point the converter has to exchange both reactive and the real power with line 1.

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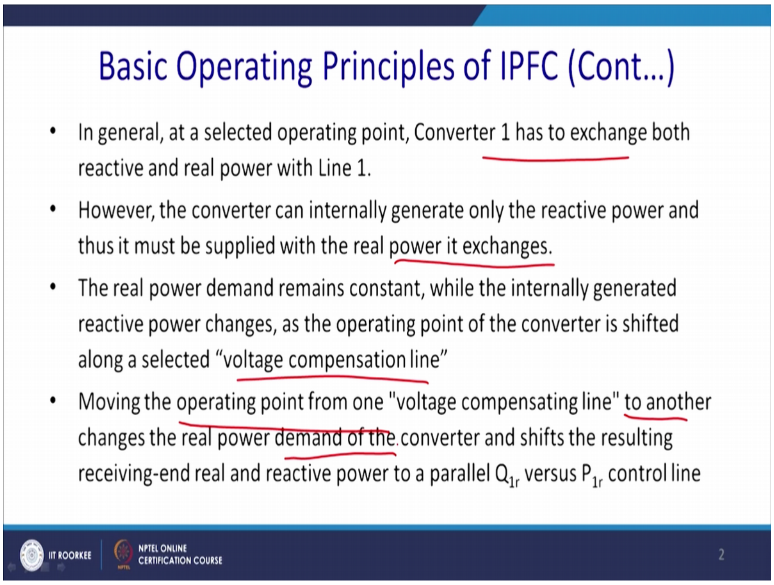

However, converter can internally generate the reactive power that is all a by managing the angle between the voltage in current and thus, it must be supplied with the real power exchange capabilities and it should exchange the real power. The real power demand remains constant while internally generated reactive power changes.

So, we can move to a point above different q and while the real power demand changes. The constant operating point of the converter shifted along the selected line of the voltage compensated line which we have seen earlier. These are all dotted quads, dotted quad changes from diameter to the upper and the lower half. So, since the length of the quads decreases so the amount of the compensation increases in when actually you have a low degree of the real power composition. As we go up reactive power flow also will be actually reduced because of the size of the quad will be reduced. Moving to the operating point, of moving operating point one point to the another operating point of the line to another change of the real power demand of the converter and shifts the resulting receiving and real and reactive power in parallel line in P 1 as well as the Q 1 of the control line.

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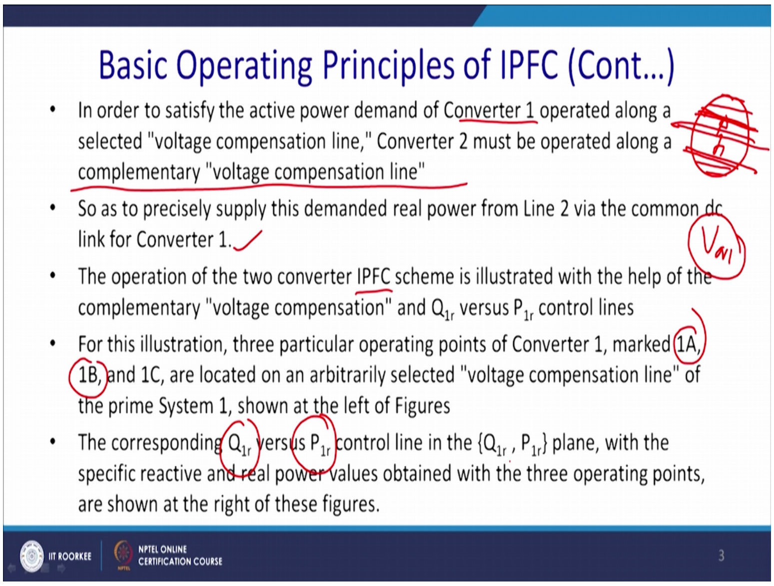

So, that is all we have understood. So, you got a quad, this is the line why there is no compensation, you go above. So, you have to give little real power or you have to absorb little real power and in this line you will have a actually compensation of the reactive power which can be manipulated by exchange of the angle. Because essentially what you are changing basically amount of V 1q and ultimately you can operate anywhere. But as you increasing so, you are compensation decreases.

So, in order to satisfy the active power demand of converter 1 operated along the selected voltage compensations line, any line here or here, even here where actually there is no composition real power. Converter 2 must be operated another complementary voltage compensation line; so, as to precisely supply this demand real power from line 2 via common dc link converter 1. The operations of the two converter IPFC scheme will, is illustrated with the help of the complementary voltage composition of Q 1 versus P 1 of the control line which will see in the next slide.

For this illustrations, actually let us take some examples three particular operating point of the converter 1 marked A1 B1 and C 1 located at the arbitrarily selected voltage compensation line. So, we will see in the next slide. So, you have to mark A1, B1, C1 these are the three operating point of IPFC converter 1 of IPFC. The corresponding Q 1r P 1r of the line of Q 1r and P r plane with the specific reactive and the real power values obtained in the three operating point and it has been shown in coming figure.

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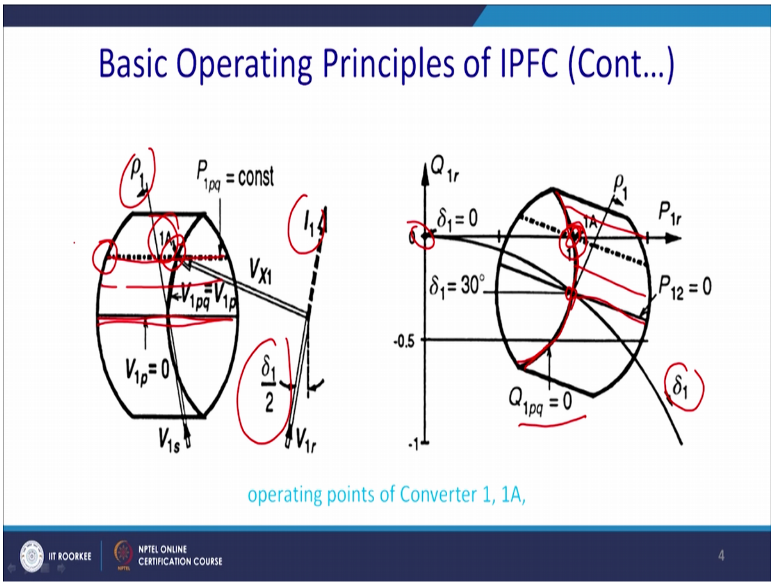

So, this one is our A1 and. So, see that here this line you know corresponds to the cost and P Q line. As said earlier when there is no exchange of the real power, this is the line and ultimately this is the row and this is this will be a different quad of where value of the P 1q is constant. And this is the I1 and this value will be actually V X1 and this angle is delta by delta 1 by 2. So, this point let us assume that this point a is basically A1 and this is the point, similarly the power corresponding to this line is P 1 equal to 0. Similarly you know this line corresponding to this, actually if you go by this line exchange of the reactive power in between this line is 0.

So, Q 1 is 0 and your operating the same operating condition that delta equal to 30 degree. So, you are here and you increasing delta then you will be shifting like this. So, this is the explanation of it then this is the case of delta equal to 0, then what happen if we wish to change, if you wish to actually move along this. So, amount of the P 1 is a constant, P 1 is a constant, if you want to move in this way. So, amount of the p q will be cost amount of the Q 1 is constant and this is the example where it is a case you know it is above. So, it is basically the absorbing the real power, this is the operating reason power A1.

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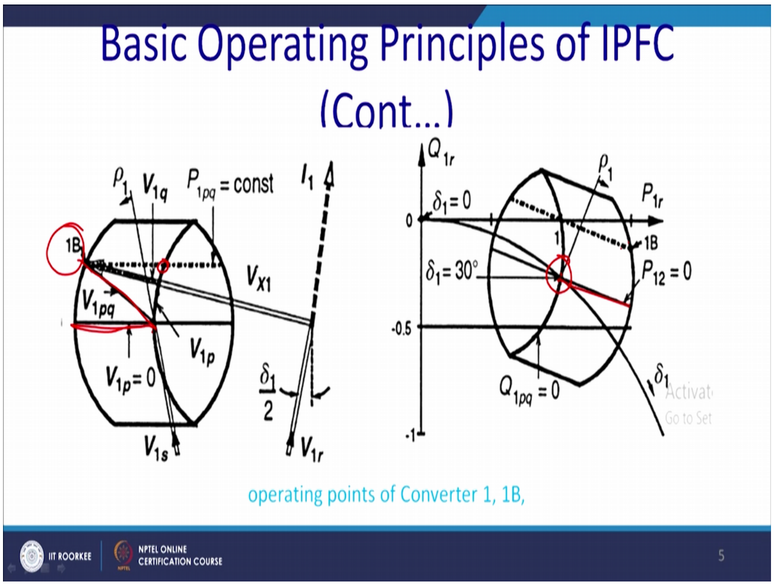

Similarly, we can find that B1, please note that what is the change in A1, A1 is actually here and we shall make it this point as P 1. So, this point becomes B1, it is same here voltage V 1 is pq, ultimately it was here you have given a voltage V 1pq; So, that this operating point shifted to B1, and thus what happened? So, ultimately were here, from here you have shifted there again to the same case, this is the actually in constant and p q line here power exchange is 0. So, ultimately you have extends some amount of the real power, some amount of the imaginary power, please see that actually this is a component where P V p1 is 0 you required to inject.

So, ultimately you have injected V 1q in this line and also you have to inject some amount of the V P 1 so that it can shifted there. So, for this reason what happened, this point which was originally uncompensated line was operating here, it has been shifted with the voltage of the pq and see that what is the amount of the actually real power been exchange between these two points and ultimately same way this is the line delta.

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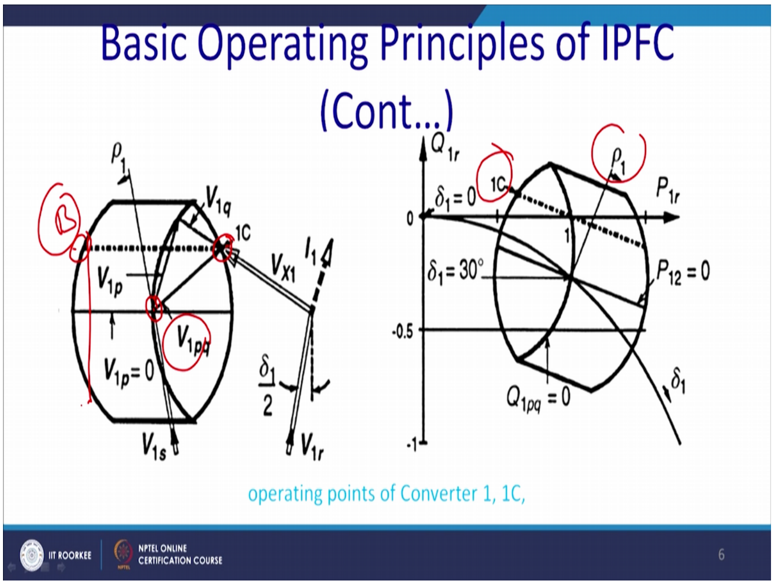

So, next let us consider that C, again same thing. So, you are here, this was being essentially, now you have shifted to this point. So, essentially your original point of location was this at delta equal to 30 degree uncompensated line.

The now you have injected this voltage V 1pq and you have moved to this point. So, ultimately what happened, so this corresponding this line becomes C and this line become 1 and same for the other cases as is been explained with the case of the A1 and B1. Let us see that in three cases what are the exchange of the real power, that is actually that is what through discuss because it cannot converter, cannot generate real power it has to actually, it has to it will take a loan from the another converter or this supply to the another converter.

Thus what we can form this discussion what we can actually take away is are the phasor diagram of the corresponding Q 2r and P 2r plane.

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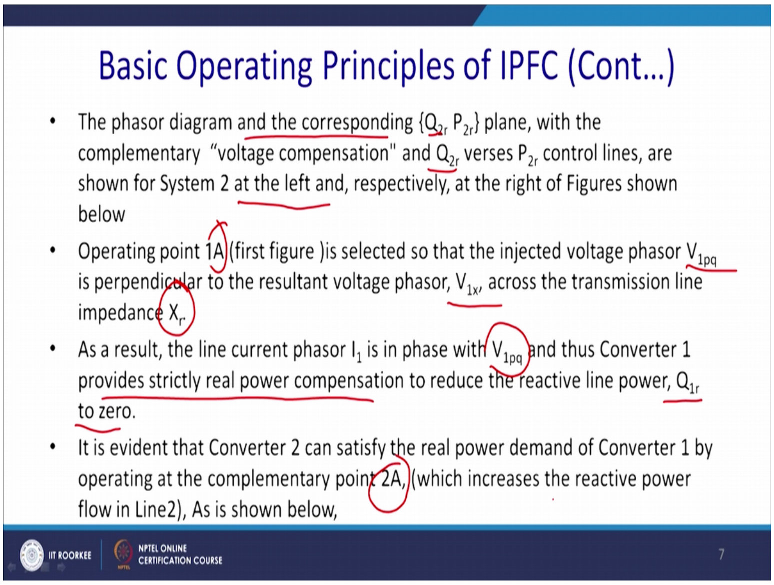

With complimentary voltage compensation of Q 2r and P 2r versus control line as shown in system 2 at the left and at the right and are the figure shown below. The operating point that is actually A1 which we have shown is selected. So, that the injected voltage phasor V 1q is perpendicular to the resultant voltage V 1x across a transmission line with an impedance receiving and the impedance is actually has been named as X r. As a result the line current of phasor I 1 is in phase with the V 1pq and thus converter 1 provides strictly the real power. Please note that provide strictly the real power compensation to reduce the reactive power line of Q 1 to 0.

So, this is the way of operating, please go back to the one then only you will understand and this is the case. So, ultimately it will inject the voltage in this way. So, what happen here this is the quad this is the line corresponds to actually 0 value of the pq and ultimately the point will be shifted here. It is evident that the converted 2 can satisfy the real power demand of converter 1 by operating at the complimentary point of the 2A which increases the reactive power of line 2 as shown in the case of A.

So, this is basically the A1 and this is basically the A2. So, ultimately what happened the reactive power of the second line we will get increased to compensate this line.

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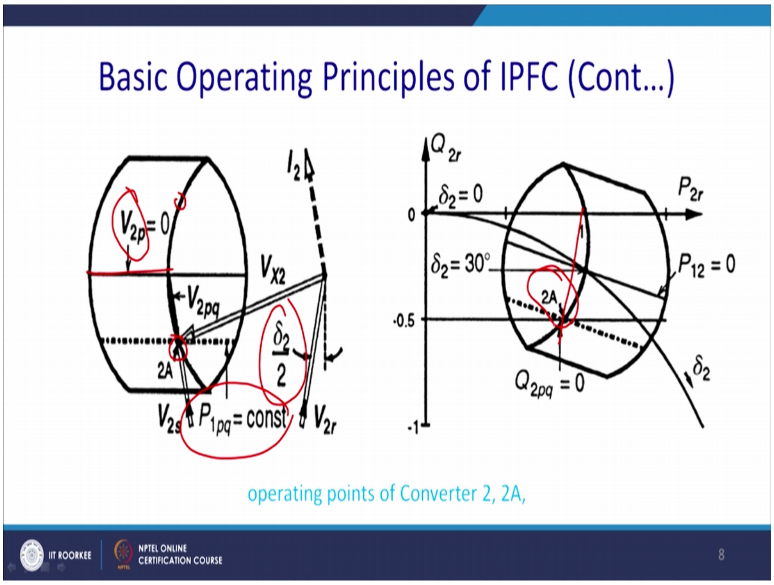

So, what happened here, you see that actually this is the line where no exchange of the real power takes place. Thus actually V 2p in phase is 0 and this is the line correspond to P 2q as this line is 2A you are shifted this line here previously, please recall that why it was A1.

So, here it was essentially A1 you are shifted to. So, you are shifted to calculate to bell board something like that. So, this is your two point 2 2A. Essentially what you do, you have a constant P 1q and you have operated at this point. So, ultimately, so this angle become unchanged, similarly you can see that this point is basically A2 and this is the operation of the converter 2, what you have seen there in converter 1, so thus it is written as A1. Same thing just you are actually it says it has been a since it, your operating here. So, it should be operating this operating point. So, should be actually within this quad.

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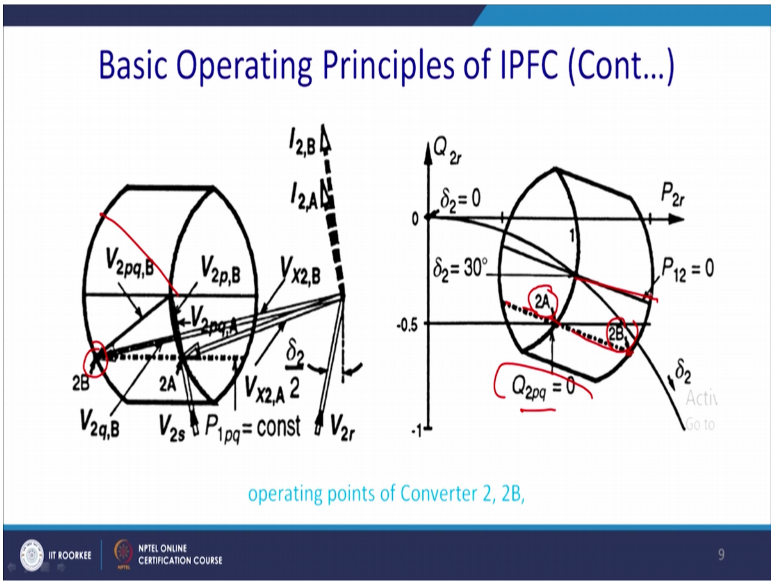

So, similarly the point B will be the same thing it will be shifted here. So, where was the point A B 1. So, it was here should has been shifted here. So, this is the line of point B2. So, other conditions what you have explained, this absolutely same the same operation as just reverse. So, ultimately it has to take power. So, it has to inject this value of the V pq is essential if with this point you can see that you have to inject little bit of positive real power here you have to absorb the real power, similarly you can operate within these two points.

So, this is was A2 further operating condition for line A1 and this one is you are 2B. So, similarly the this is the case of the line why real power exchange, the imaginary power exchange is 0 and this is the actually the real power exchange is 0, here it will go to the according to the magnitude.

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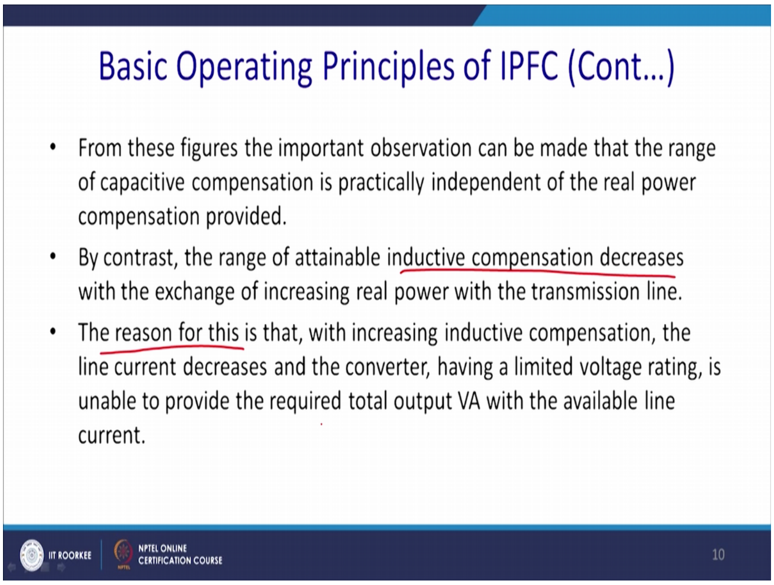

Thus from the discussions similarly it will be for the 2C, from this figures the important observation can be made with the range of the capacitive compensation in particularly independent of the real power compensation provided. So, it can have a separate independent power flow of reactive and the real power, by contrast the range of that attainable inductive compensation decreases with the exchange of the increase of the real power with the composition line.

So, this is one of the disadvantage. So, it can compensate capacity power quite a well, but it will not have seen the length of the quad decreases. Since you have a actually increase it exchanging the real power. So, inductive capability will be reduced in case of, but generally lot are inductive. So, for this is an IPFC actually put it so the very dominus position in our facts devices. For this session the reason for is that with the increasing inductive compensation the line current decreases. So, we have assumed that line current actually even constant and the converter having a limited voltage rating.

So, you cannot increase the value of the voltage. So, it has to have a (Refer Time: 16:14) device, actually comparative to restrict yourself to a particular voltage rating and is unable to provide the required total output VA in the available line current. So, it is a very good capacitive valve compensate.

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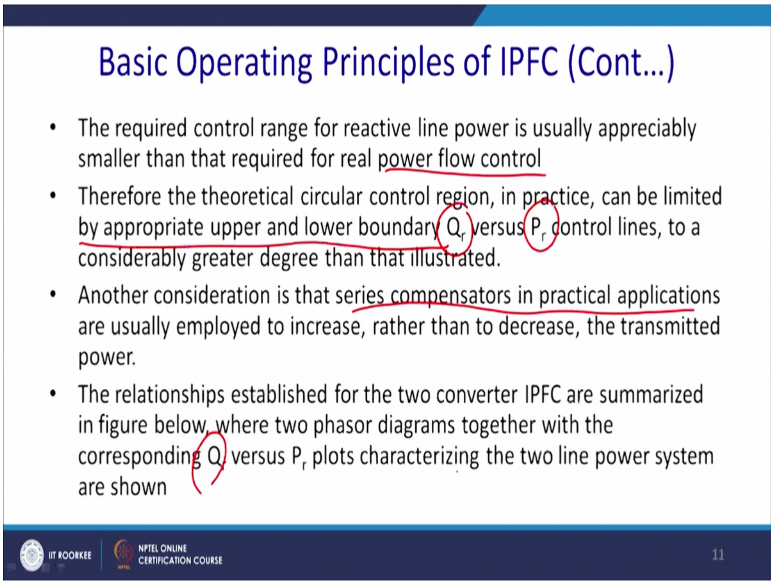

The required control range for the reactive and the reactive line power is usually appreciable is smaller than required for the real power flow control, generally it has to manage more, more and more real power than the reactive power. Therefore, theoretically the circular region which we have shown that p and q are balanced, but it is not so.

So, basically we have to (Refer Time: 17:01) it the diameter along the P, thus it becomes ellipse. Circular is in practice can be limited to a appropriate upper and the lower boundary of Q r and the P r line control, to considerably get a degree that has been illustrated. So, another consideration is that is series compensation in practical applications are usually employed to increase rather decrease the transmission power.

Most of the cases rather accept the fault we require to increase the transmitted power, the relationship is established for the two converter of IPFC are summarized in the figure below next slide; where two phasor diagrams together with corresponding sending and reactive power that is Q r versus P r plot characterizing that two line power system will be shown.

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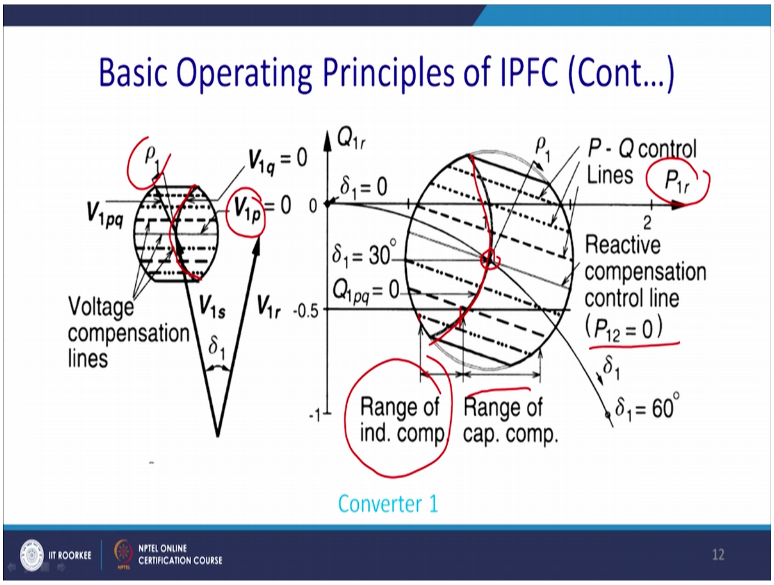

So, this is the case of where both 1 and 2 had been is merged. So, this is essentially the voltage compensation line, the this is the angle row 1 and this is the line corresponds to the actually 0 injection of the Q V q1. So, there is no reactive power capability.

Similarly, this diameter corresponds to the 0 injection of the V p1 and your operating here that is V s1 and delta 1 and similarly you know this is the, this is operating point here. And this is actually, essentially what it has been shown this much is the inductive region of compensations and these huge area is the capacitive reason of compensation. So, this is the drawn line you know. So, here this line actually does not compensate this is the operation of the unity power factor.

So, you take this operating point this is assume that you are operating here and you can see that how it will be changing. Similarly this region reactive compensation line control where actually you have no exchange of the real power P 12 equal to 0 and here this is actually the p q line of P 1, P r1 and this is a way of phasor diagram of converter 1. So, thus it will be actually the something like their image of converter 2.

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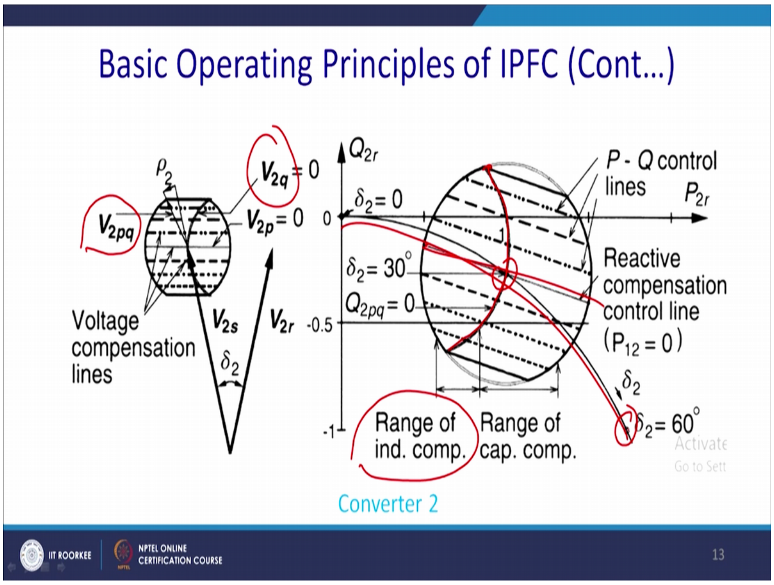

So, see that, so it will change. So, operating point will be the same. So, you know it will be actually V 2q, now this will be the delta and this is the this quads are the ultimately it will make a parallel loop preferred. So, basically you will have a cylinder kind of thing and this lines essentially are the voltage line compensations, to this line corresponds to similarly the no exchange of the real power between to convert V 2q is 0 and this line corresponds to again the no exchange of the real power V 2p is 0.

So, ultimately operating here and these are the line P Q and where this line corresponds to no exchange of the real power and this is a region of the inductive region, and this is a region of the conducting region and these value is corresponds to. This is a delta line how this actually circular of influence will be changing, with the change of the delta and essentially this is the line corresponds to no real power, no reactive power exchange. So, if you it where operating this region so it will be operating this region, as simple as that.

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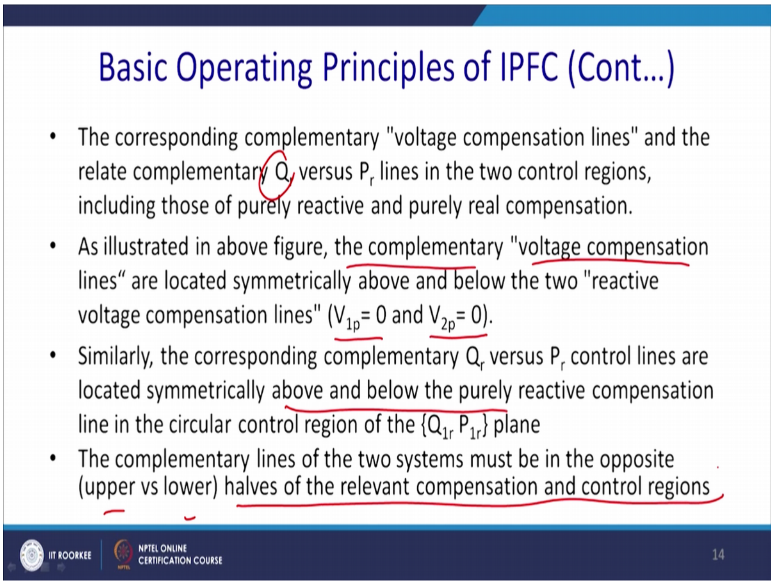

Corresponding to the complementary voltage compensation line and the rated complementary Q r versus P r line in the two region including those are the purely reactive and the real power compensation can be feeded. At is at being last stated in the previous figure the complementary voltage compensations lines are located symmetrically the above and the below two reactive voltage compensation line that is V 1p 0 and V 2p 0. Similarly the corresponding complementary Q r versus P r control lines, are located symmetrically above and below the purely reactive compensation line in the circular control region of Q 1r and the P 1r plane.

The complementary lines of the two system once we opposite of a versus, you adjust it is complementary half’s of the relevant compensation of the control region.

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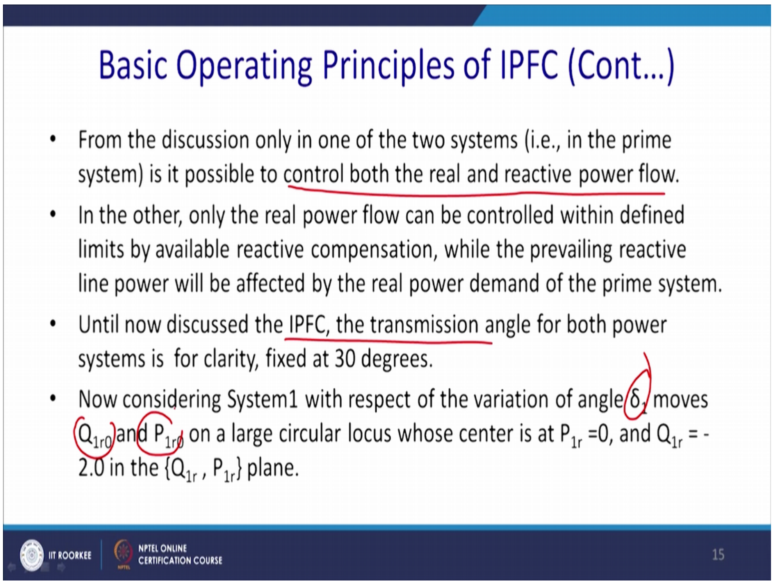

From the discussions only one of the two system that when in the that when the prime system. It is possible to control both real and reactive power flow, on the other hand only real power flow can be controlled within a defined line limits by available reactive power compensation. While prevailing reactive power line who will be affecting by the real power demand of the primary system, as we have seen that actually the quad actually sinking as we are try to actually supply more and more real power for one system to another system.

Until now the IPFC discussed for both power system angle for delta equal to 30 degree and same discussion can be extended for another angle lets 60 degree, 45 degree or any other angle.

Now, considering the system one with respect to variation of angle delta 1 moves to Q 10 to P 1r 0. On a larger circular locus whose centre is at P r1 0 and Q r1 equal to 2 in the plane let us see that what happened.

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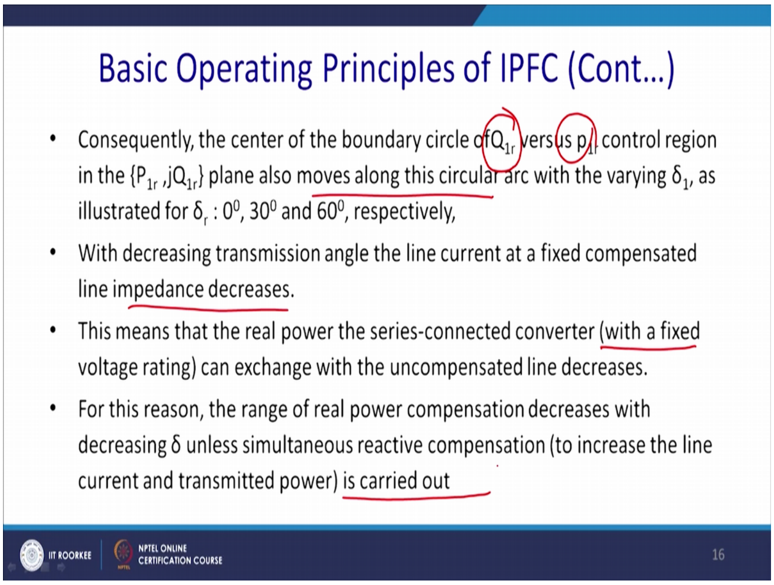

And consequently the centre of the boundary of the circle Q 1r versus P 1r control region in the P 1, P 1r and Q 1r plane also moves along the circular r without varying delta one which we have actually find we will find here. So, this is the varying delta, with decreasing the transmission line angle the line current are fixed compensation fix compensated line impedance decreases. So, length of the line become less, this means that the real power series connected converter with the fixed voltage rating can exchange with the uncompensated line decreases, for this session the range of the real power compensation decreases with decreasing delta unless simultaneous reactive power compensations has been put.

So, we can say that the simultaneous reactive power compensation to increase the line current of the transmitted power is carried out. So, this is basically the some observation we can do for normal facts devices fitted with the IPFC.

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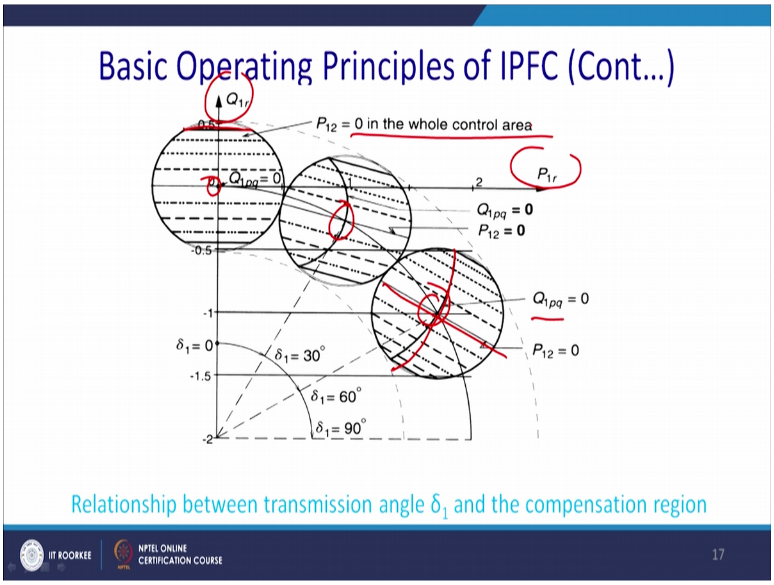

So, this is the case you know you can see that is a case delta equal to 0. So, this is a you are circle of influence and where P 12 equal to 0 in whole area you cannot exchange any real power, similarly you know when you shift gradually, you know actually operating here.

So, we can see that actually, this line corresponds to reactive power compensation equal to 0 and this diameter corresponds to real power composition equal to 0. So, this is a case which we have discussed. Actually for 60 degree is a case we have discussed throughout our discussion in the case of the 30 degree in that way you can see that this is basically the P r and Q r. And so this is a line at 0.5 per unit.

So, this is the line where actually P 12 equal to 0 and whole controllable area. So, this actually here and thus actually gradually we can see that is both line actually get shifted. So, for this session this is a relationship of UPQC or IPFC with the changing delta. So, you can see that actually you increasing delta it has a whole range of operations of the P Q.

So, the control structure of IPFC is similar of the UPFC which we have discussed before the IPFC. With appropriate change of the control variables necessary to necessary crusted imposed by a limiting the power transfer because power transfer will takes place between two lines, there in UPFC it will fed to the shunt part and it will be injected through the serious for the maximum cases.

A possible IPFC control will be shown in the next block diagram, for this structures assumption of the previous sections stipulating the system 1 with IPFC converter 1 is V p consider that is a prime. And requiring the independent control both real and reactive power and of subsequently the logic of the second IPFC will be followed, the stipulation makes the control of the converter functionally somewhat different, will see that. In practice two converters, control would be identical with the control input putting converter.

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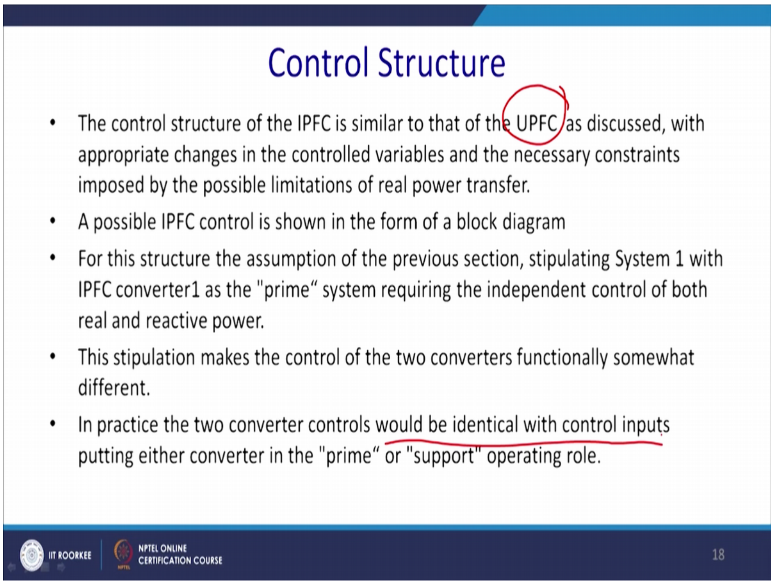

One converter as prime and another converter will be on support. So, ultimately power demand ultimately we will control basically p and q of one particular line and thus whatever p required to be fed that is better be fed from the other line. In that way you are maintaining the power demand real and reactive power demand by the one line because since you are sending the real power. So, ultimately you will be restricted by your actually demand of the supporting line. So, see that this is a control block diagram of the IPFC.

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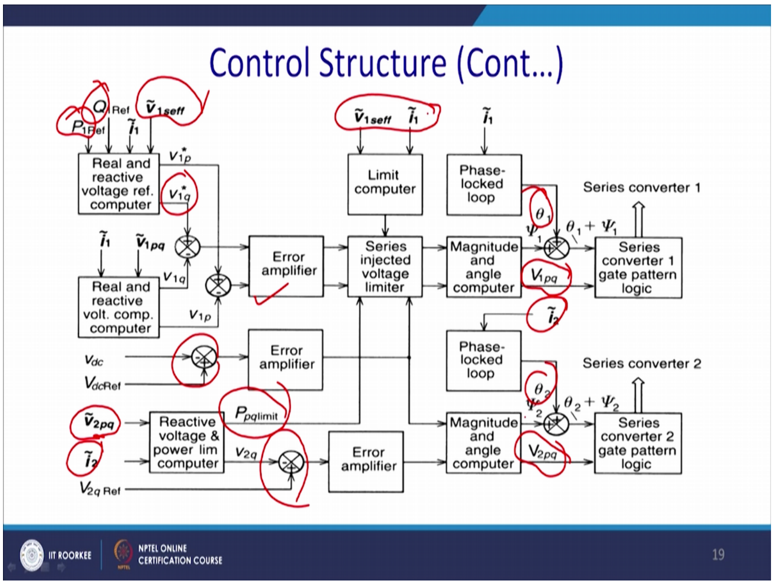

So, this is actually Q 1ref and P 1ref and this I 1 delta an effectively actually this one is effective sending end voltage that is V 1 effective. And from there you will compute the in phase component of the voltage injection and the quadrature component of the voltage injection, that is essentially V 1p star and the V q star. And you will sends this value I 1 and V q1 and ultimately you will compare and I will be fed to the P i controller this is essentially an error amplifier and. So, an you require to maintain the d c bus voltage to meet the losses and exchange of the real power.

So, V dc and the v d c ref from there we will have any error amplifier and what happened similarly for the this is for the 1 and we assume that 1 is prime and 2 is supportive. Similarly, V 2pq V 2q will be have a some exchange of the power and this is v i and this will be i q and from there actually you will get the reactive power. Since it can injects the second converter is independent to control the reactive power. So, this logic will be same, but for the real power it has its limited by the power handling capability of the real power thus it will have a P Q limit and that will be actually fed to this actually the sends inject voltage limiter.

So, essentially it will fed to the V i controller, you have a actually essential to this limit will be said by v s1 and I s1 and thus it will actually generate the amount of the injections of the voltage required. And this will be the magnitude and the angle computing computer and this will compute the amount of the V 1pq require and will sends actually i 1, from their actually who will have a PLL loop from PLL loop will actually compute theta. Psi plus theta 1 essential you we will be the effective phase shift given to the voltage P 1 q and that will be actually fed to the inverter, in inverter will actually inject that voltage.

Similarly, we will have a i 2 phase lock loop from their actually theta 2 will be computed and we will have a error amount of this things and from there actually will compute the amount of the p q is required. So, it will be fed here so ultimately you get we will generate actually V 2pq and same voltage and angle will be fed to the second converter this is the way of operations of the DC of this actually 2 interconnected IPFC.

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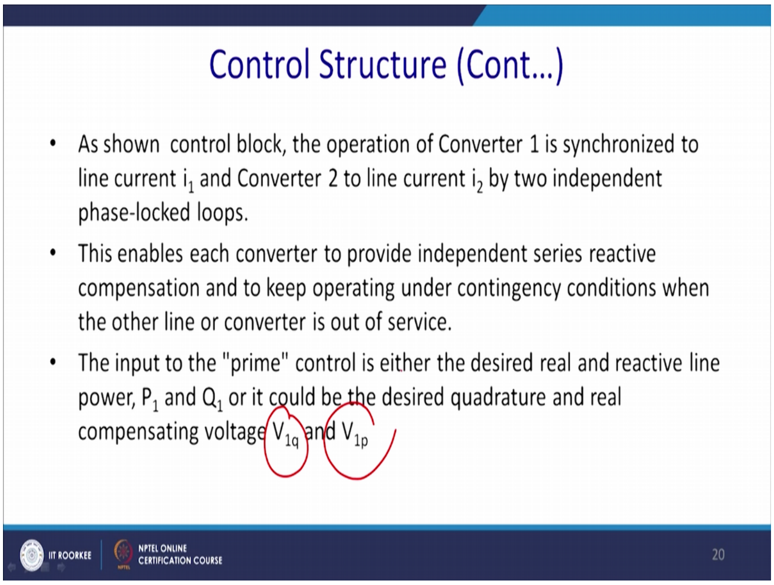

So, as shown in the control block the converter 1 is synchronize to the line current i 1 and converter to has to be synchronize with the line current i 2, V 2 independent phase lock loop we assume that there is no phase relation established between the two entities.

It enables each converter provide the independent reactive power compensation to keep the operating voltage, operating conditions and the contingency 2 as a independent identities. The input of the prime control is either is desired the real and the reactive line power of P 1 and Q 1 or it could be desired in a quadrature of V p1 or V 1p.

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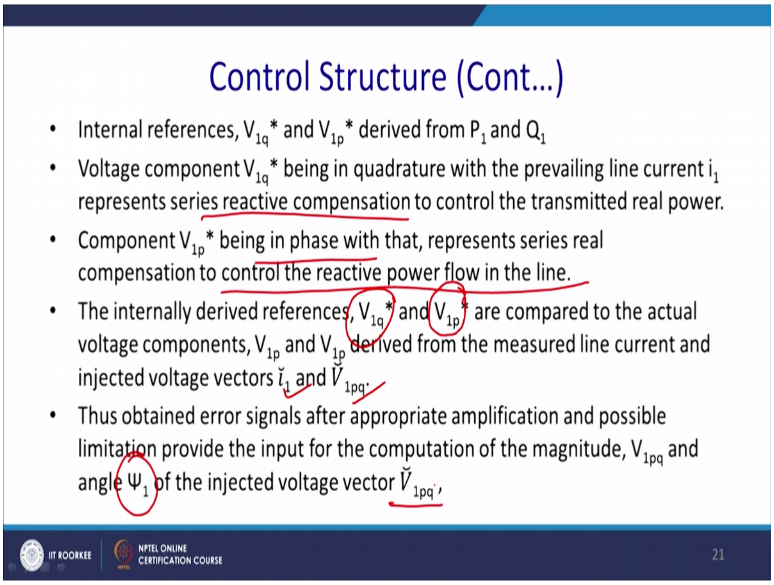

So, internal reference that is V 1q V 1p from the P 1 and P q will be generated. The component of the V 1q being quadrature, with the prevailing line current i 1 represents the reactive compensation to control the transported real power. The component V 1p star phase with that represents the series real power, series real power compensation to control the reactive power flow of the line.

So, it will be just opposite to the it is a cross relationship, internally provided reference of V 1q and the V 1p are compared with actuals of V 1p and V 1q and it is fitted to the p i controller and thus we generate these two logics. And thus obtained an error signal after appropriate amplifications is possible, and with thus generate actually psi 1 and corresponding with the voltage of V p1.

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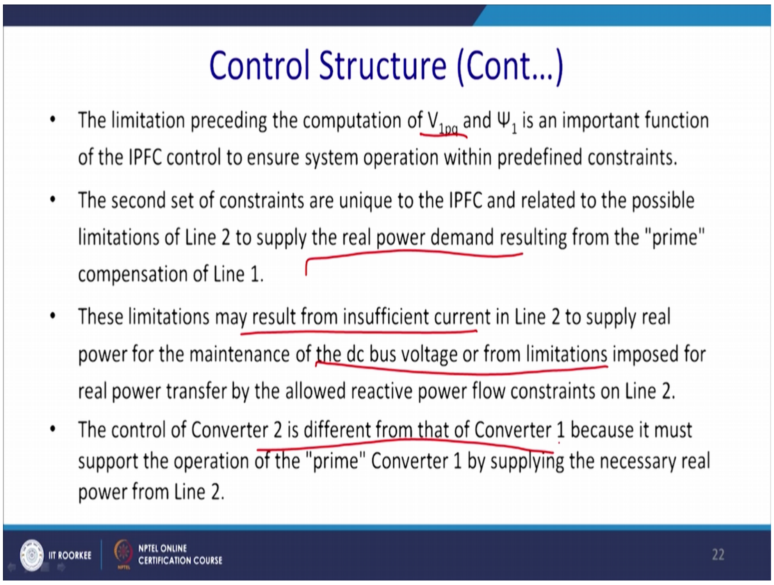

Similarly, so limitation proceeding the computation of the V 1pq and psi 1 is an important function of IPFC control to ensure the system operation within the predefined constant. The second set of constant are unique to IPFC are related to the possible limit of line to carry the demand of the spine blinds compensations. This limitations may results insufficient current to line to supply the real power, to maintain it is the DC bus voltage from the limitation imposed by the real power.

So, this is something by unique features that has to be considered while designing the IPFC, the control of the converter to is different from the converter 1 because it must support the operating operation of the prime IPFC and it has to fed the actually power demanded by the IPFC.

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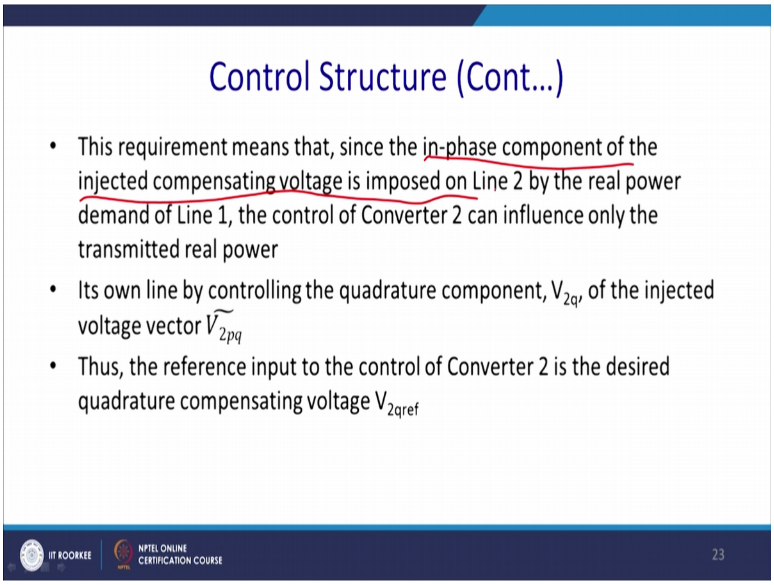

Thus it requirement means that since in phase component of the injected compensation voltage is imposed on the line 2 by real power demand line 1, the control of the converter 2 can influence only the transmitted real power. It is all line controlling the quadrature component of the V 2q of the injected voltage vector V 2pq thus the reference input of the control of the converter 2 is desire quadrature compensating voltage of the V 2 qRef. So, the reference voltage of P 2qRef is compared with the V 2q derived from the p i controller.

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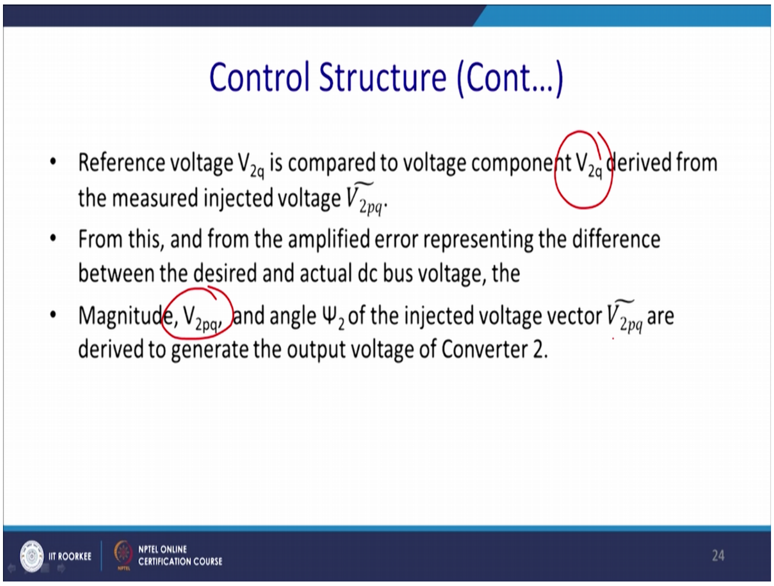

And from this from the amplitude of the error representing the difference between the desire and the actual bus voltage is computed.

The magnitude of the V pq with angle psi 2 is injected and converted second converter is operated. Thank you for your attention we thus finished IPFC in details, we shall continue to our next class that will be our concluding class. We shall take a case study in next class and we shall see that in a particular area how different kind of facts devices and its synchronization operation can give you an appropriate power monitoring control and stability operations. And we shall also discuss the advantage and disadvantage of different kind of facts devices and its basic philosophy.

Thank you for your kind attention.