Switched Mode Power Conversion
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Lecture - 36
Regulation of Multiple Outputs – II

Good day to all of you, recall that we were discussing how to regulate multiple output power supplies. Out of the multiple outputs, one of the output is fed back and that would be the controlled output. The remaining outputs which are uncontrolled needs to be locally regulated and in this respect we discussed few measures.

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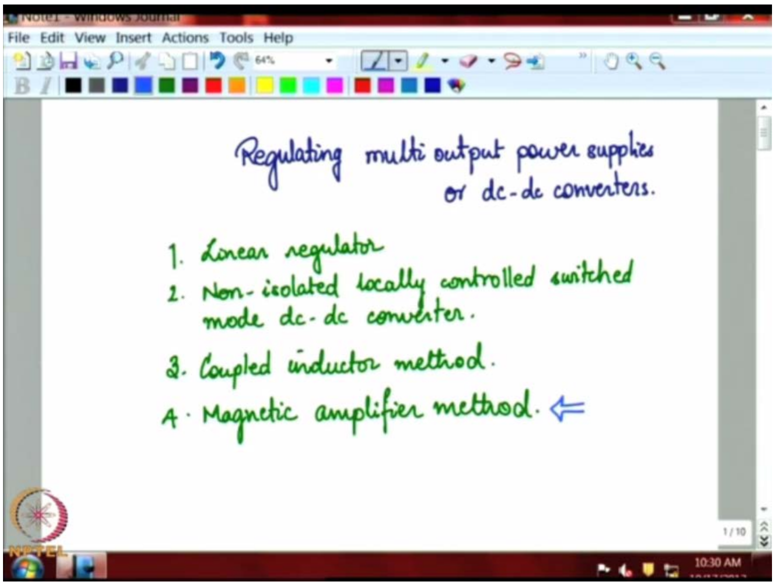

And the following were the measures that we discussed in regulating multiple output power supplies or dc to dc converters. So, the first one which we discussed was based ON linear regulator, then we discuss non isolated locally controlled switched mode dc - dc converters in place of the linear regulators. We discussed the coupled integrator, sorry the coupled inductor method. And then we were discussing the process of trying to understand the magnetic amplifier method. We shall try to continue this discussion and complete this discussion in this class. And then take up the next topic.

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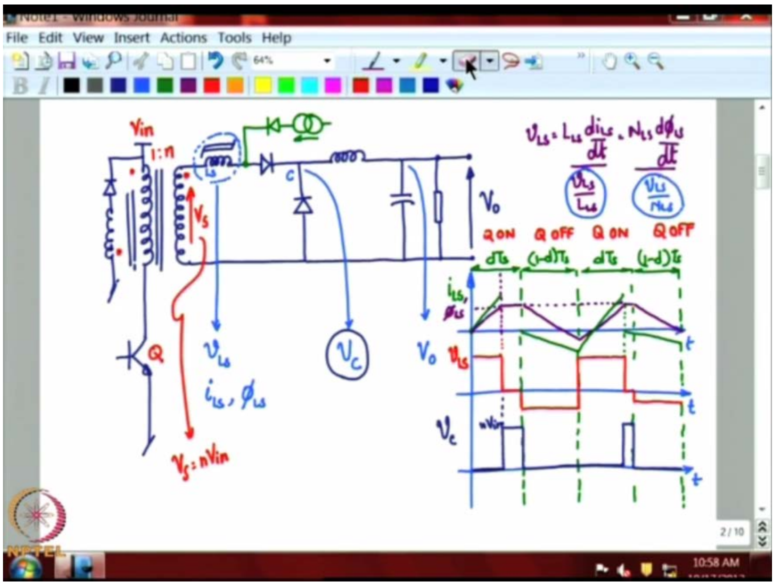

So, if we take the case of the magnetic amplifier base method, we discussed that we will be, I will just draw here now only one winding, we assume that there may be other windings. There is one saturable inductor and we have and then the regular buck converter which is present in other forward winding converters. It may also be fly back winding, a fly back based of based output. Now at this point we trying to interpose a current source, which is derived from the output and is in it is going to direct current in this direction. As shown now let us look at this component the saturable inductor component, the voltage across that this is called L s.

The current through that and of course, the flux in it t, then as a consequence let us look at the voltage at the point, we will call the point c voltage at c. And then voltage v naught at the output, let us have a look at these parameters of the circuit these points of the circuit where we can study the waveforms and try to understand the, this particular magnetic amplifier circuit. And after, we do that let us look at how we are going to incorporate this portion of the current, current controlled current source here in the circuit.

So, we shall plot the waveforms here so one by one, let us not forget the dot polarities is the forward converter. Now when the switch here is on, this dot is positive, and this is positive. And initially the inductance acts as an impedance ON open circuit, and does not allow the voltage to appear at this point. In order to forward bias this diode or appear at this point till that gets saturated. So, let us look at the current and the voltage wave shape of the inductor l s. So, let us divide it into four parts, the time scale into four parts, where this is d T s 1 minus d T s d T s 1 minus d T s.

These are the times and during if you say this is q, this is v, in during this time Q is on, during this time Q is OFF, Q ON Q OFF. And now the moment Q goes ON the voltage vs, let us say this is one is to n. So, the voltage vs would be n times v in with the dot end positive now this diode is freewheeling, this diode is freewheeling, because of the inductance and the output inductor stored energy. So, this point is ground potential for this diode and this voltage is positive, this voltage is positive at the dot end.

So, there is a current that is going to flow through this could be positive side of the anode, of the diode. This diode is forward biased and you can have a current flow through this as long as the current through this loop is lesser than the current of this loop this diode will conduct. So, let us assume that, the current through this is lesser than the output load current, which means this inductor current i L s is increasing. So, let us say i L s is increasing like that, at the same time, let us say the flux.

Flux is also having the same pattern increasing along with the current only the rates are different v L s is equal to L L S dils by d t which is equal to nls the turns of the, turns of the winding d pi l s by d t. So, if you look at these two equations, the rate for the current is v L s by L L S, and the rate for the flux is v L s by n L s. So, these two rates are the ones which dictate the slope v L s by L L S dictates the slope of i L s. and v L s by n L s dictates the slope of the flux within the core.

However, as the in the linear region L L S is constant, v L s is constant is the linear slope, v L s is the constant again, n L s is the constant that is also the linear slope. Now let us say that the saturation limit, the flux saturation limit is at that point. So, which which means that flux flattens out, the voltage across the inductor becomes 0. The moment the voltage across the inductor becomes 0, the this diode the voltage through this diode will appear at v c, and reverse bias this diode, this diode switches OFF and entire load inductor current commutates as the input current. So, what will flow through i L s i L s which is now acting as a shorted which is acting like a short circuit, will pass the current which is flowing through the output inductor as is. Now during that time the voltage v naught, the voltage v L s which was positive and which was the positive value.

Let us not clutter it up let me just up to this time and at this point of time, it goes to 0 because this diode conducts. So, here the L s s the saturable inductor is acting as an impedance during this time.

The flux as saturated inductor the saturable inductor is no longer acting as the inductor but as the plain wire the voltage comes up to this point v c turns OFF this diode. So, the voltage across the inductor is saturable inductor is 0. And, if you look at the voltage across, look at the voltage v c across this diode v c, when the diode was freewheeling up to this point. Let us say it is an ideal diode the voltage v c was 0 and then once the inductor saturates the entire secondary voltage N v in appears at this point. Now this transistor Q is turned OFF, the moment the transistor Q is turned OFF there is the reversal of polarity in the primary.

And therefore, the reversal of polarity in the secondary, the primary there is a demagnetizing winding which tries to take care of flux in the primary transformer. Now during the time when this is OFF, the voltage across this inductance should be negative. In order to achieve volt second balance now, how is that brought about let us say, there is the current which is flowing from this current source.

How we get the current source we see that later, let us say that the current flows through like this through the inductor. So, the current flows through the inductor in this fashion look at this equation. When the current flow is opposite direction meaning the negative current, therefore, a negative slope. The voltage across the inductor becomes negative, let me draw the current through the inductor starts flowing in this direction, let us say we give a linear current increase.

Now based ON this slope linear current increase up to some point, let us say, let us say the current flows in this fashion. And therefore, has a result the flux also goes, goes down by v L s by N L s. Let us say it goes and settles down at that point, now because the flux and the current are negative, the rates are negative, you have a voltage which is negative. From the fara days equation, let us draw that so this goes negative, now if the current rates are such that, the current rate are such that this negative value is less than n times v in with the dot end negative, non dot end positive.

Then the remaining voltage will appear across this diode as reverse bias, because this is conducting and this diode is turned OFF. Therefore, you can be assured that all the current flows only in this direction, so now during the time when the transistor was OFF. This is what was happening within the saturable inductor, what is the current during this time i L s looks like there is a jump from here to here but let us look at this later. Now when onset of the next period, the voltage again becomes positive, because the moment Q is turned ON the dot end becomes positive, the dot end ON the secondary side becomes positive, n v in that appears across the inductor.

The inductor has from the saturation, saturation state has reached nonsaturating state, because the flux has decreased, because we have provided the negative current. And it would stay there, till at point where the flux, starts rising and at some point again it reaches the saturating state. And like before the current is also increasing at more or less the same this is increasing, at more or less the same slope or same rate as this, because the slope of the current is determined by v l s by L L s. It was same as before and the slope of the flux is determined by v L s by n L s which is same as before.

However, the starting point can be different, for the flux, and how can the starting point be different, by giving different negative slope rates of the current by adjusting the value of the current source. The current which is driven during the OFF condition, the flux can be brought down to the different values either to 0 or less than 0 or still up. And as a result the starting point for the flux can be different, and when it goes at the same rate it go an intersect at different time points in the d T s ON time. Like this so at the point when it intersects the saturation flux value, the voltage becomes 0, the moment the voltage becomes 0 the whole secondary voltage gets passed ON to the point v c. And v c would look like this and the second when, when it is when the Q is again switched OFF again the voltage here would go positive or negative.

Depending upon the current flowing through L L S, but we are always going to allow the current flowing in only one direction, which is in the opposite direction to what was flowing, when the transistor Q was ON. And therefore, the voltage is always be negative as compared. To this in order to maintain volt second balance so by controlling the rate, by controlling the rate of current that is going to flow in the saturable inductor in the reverse direction. You can control the amount of voltage that is appearing across the negative, voltage that appears across the inductor. And as a result controls the flux rate within the core and you can make it at the time at the end of the period. You can make it intersect or come down to or reset to a value 0 or negative or positive. So, for the next period a new period the starting points can be different, and as a result you notice here different starting points, of the flux will give you different pulse width.

You see the different starting points for the flux at this you will get the different smaller pulse width. So, the starting point of the flux is higher up in the y axis you would get a larger pulse width. If the starting point is lower down in the y axis negative and lower towards the minus 5 sat then the pulse width which appears at v c is smaller. So, this is some kind of a pulse width modulation which is happening locally by means of injecting different current rates during the OFF time of Q. So, this is the essential principle, now what is happening to i L s current during this times, during these times. It will just take the same value of the inductor that was flowing through and which gets commutated from this diode. So, during the times when v c is high the inductor current commutes to i L s to understand this better, let us clear some portion of the screen here.

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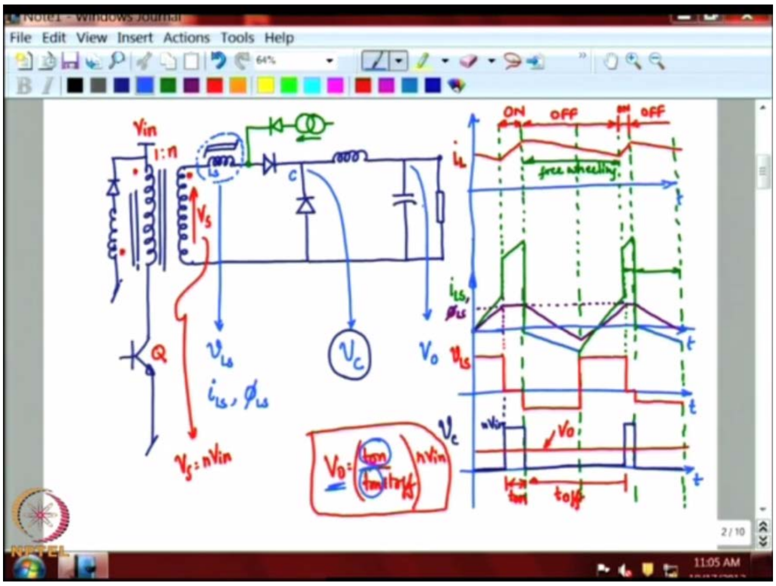

And let us extend so we know that, so let me extend this axis a bit, this t now consider i L, now i L i am going to put that in red color. So, the current through the inductor, is going to flow in this fashion, so as for as the inductor is concerned. This portion is the time inductor will considered it is on, and this portion of the time, the inductor will considered as OFF time and ON time, OFF time. So, the inductor current ON the steady state you would see that it is going in this fashion grows at, because this entire period is entire time with freewheeling time. This entire time, this freewheeling time as can be seeing here.

During this time this diode is always conducting and an inductor is freewheeling for the entire portion. Only during this time you have freewheeling time and the energy is put into the inductor, so so ON and it could be in this fashion. So, during this time the inductor current the inductor current will become the, become the current for i L s. So i L s will take ON shape like this, so shape like this so that could be the shape of the inductor current, could be the shape of the current i L s to the saturating inductor.So, from this we see that the voltage at this is point is a kind of the pulse width modulator voltage. Where pulse width can be adjusted by the current flow which gives output into need go through saturable inductor. And output voltage is nothing but average of the voltage just like buck converter operation.

The average of voltage at this point is the voltage which occurs here which is nothing but d into v c. So, the average is given in this fashion and this is, if this you consider as the ON time t ON now, and this is considered as the OFF time, t OFF then v naught t will be equal to t ON by t ON plus t OFF into n into V i n. Now that could be the voltage at the output, remember that by controlling the weight of flow here, we are able to control the ON time. So, this is controllable so like a variable duty cycle function. And therefore, the output can be regulated by controlling this t ON which means by controlling this current rate. That is precisely what will be doing controlling this current will control basically the t ON of the local switching which will control the output voltage. Now coming to an our operable circuit let us draw the circuit.

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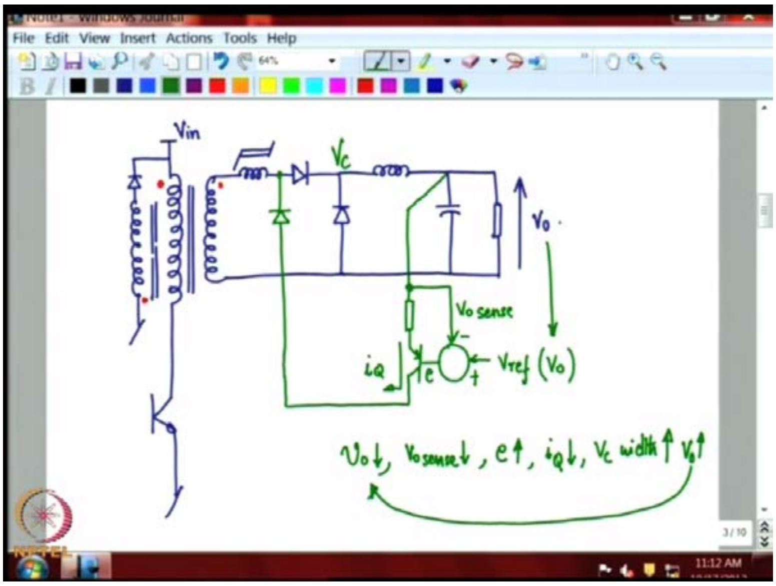

Now, that we have understood the principle we have a forward converter, and we have the saturable inductor and followed by the regular buck topology of the forward converter. In this fashion this is the saturable inductor v in and we have a clock, polarities likewise. Now, let may draw the injected current in a different color at this point let us inject current in this fashion? Now, let us draw the current from the output in this fashion, the resistor and let us say you have p n p transistor, which act as a switch not switch a linear resistance.

So, what happens here is that based ON the gate drive here the transistor start getting into different operating point along its load line and tries to draw that current, and pass that current ON to this portion of the circuit. Now how do we give this gate drive this gate drive, should be such that the bias current base current, biases this transistor at an appropriate operating point. Such that just that correct amount of current is flowing through the inductor in negative direction to reset this core, to an appropriate flex level for starting in the next cycle, when the switch is on.

Let us have reference, now what should this reference represent it, should represent v naught which is this. So, let us this is the set reference of v naught and sense this v naught, this is v naught sense this is minus, this is plus. Now what happens here now let us say that the v naught has decreased. So, the movement v naught has decreased this has become lesser this will become more, so once this once this has increased this will start getting biased towards cut OFF.

And asks this starts getting biased towards cut OFF, the current flow here reduces. Once the current flow here reduces, the resetting action ON this inductor is reduced, and the flux reduces set at slower rate. Therefore, by the end of period comes the flux would have reset to a higher value than before, and because it has reset to higher value as you saw previously as flux resets higher at in the y axis the pulse width increases. Once the pulse width increases the output voltage will increase.

So, that is the control action that is happening here so if v naught decreases v naught sense decreases v naught sense decreases and let me call this one as e error error increases. And let us say the current i Q, the i Q current decreases because the p n p is not biased more towards cutoff and as a result pulse v c width v c is this one v c width increases and therefore, v naught increases. So, this, this tries to bring this back to the original condition likewise v naught increases v naught sense increases error decreases I Q increases v c width decreases and v naught is decreased and brought back to the original state. So, this is the control action that is happening now let us say, we can try to implement this with an op amp. So, let may make some space here, let me try to implement this portion with an op amp.

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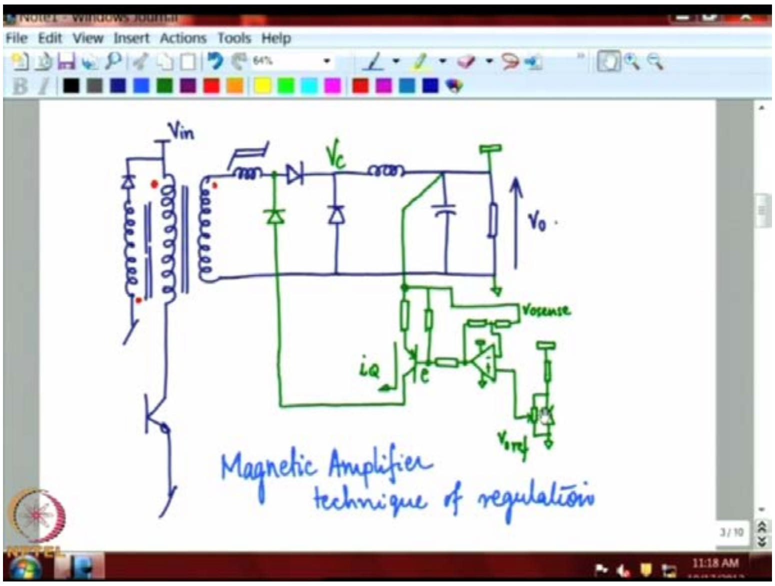

The resistance ON op amp minus plus and we could have a reference which is enough in this fashion. So I am labeling it such that notice that this point is same, as this point and likewise this point same as this point, and the op amp will also be driven likewise, from the output. So, it is self-contained and and the op amp so this is an inverting op amp inverting op amp, which is powered from the v naught plus and v naught ground, this v naught plus v naught ground first input of op amp is given from a zener, this is v naught reference that we are trying to give. So, from the v naught output and ground un regulated which ultimately get regulated, you can generate a reference using zener, which gives more precise regulation than what you achieve output.

And then that is given through a part and value is set here positive point of op amp that could be a reference point then to the negative point, come from v naught itself. So, the v naught line is taken from here that will be the v naught sense v naught sense, and through the non-inverting amplifier here. So, v naught sense decreases this output would increases, and because of the output increases, this transistor which is a p n p transistor get biased towards the more towards the cutoff. And as result what is belongs from the output is a laser current, which flowing through this and because the laser current resetting this lesser. And therefore, the next cycle we see has higher pulse width and therefore, v naught is brought back to the original state.

So, this would be the complete circuit for possible magnetic amplifier technique, magnetic amplifier technique of regulation in the local loop. So, the regulation is in the local loop this duty cycle controlled is based ON the control winding loop. Whatever that happen this inductor is acting as control for this particular output through this means so now that we have studied how various means of regulating the output of the multi output dc, dc converter. We shall look at some applications where you may not want to regulate the output voltage but probably may want to regulate the current, or you may want to regulate both the current and the voltage. So, how to be go about current control to the next topic that I want to take up I introduce you to is…

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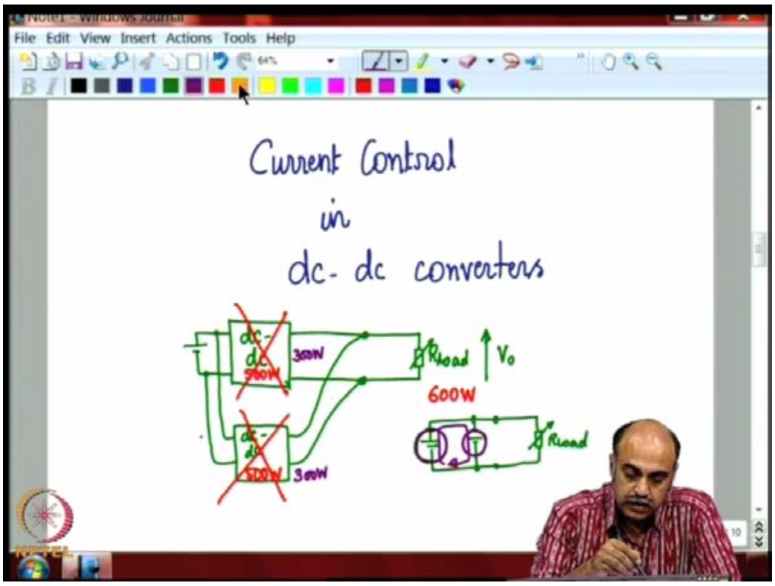

So, now that we had studied how variously regulating output of multiple dc dc converters. We shall look at some applications, you may not want to regulate voltage probably where we may use this current control is normal that we have only voltage control and should voltage control is sufficient. However, we will see application where current control is essential and necessary also let us say for an example 2 power supplies you have power supply 1 1 dc dc converter, 1 dc dc converter. And that is applying a load and this is, are load v naught. Now suppose let us say, this particular power supply is not fully able to supply this load power. Load power can vary so let us say this power supply has maximum limit of let us say 500 watts. And let us say that, you need 750 watts here the load can swing from 0 to 750 watts. So, up to 500 watts when the load here swings up to 500 watts the variable load, this dc dc converter is sufficient and it can where the load.

However, the moment this load increases beyond 750 watts this dc dc converter will not able to handle it. One method is that to design a dc dc converter which is rated for 750 watts or more than 750 watts. But, let us say in an inventory we have only dc dc converter designed and made for only 500 watts is it possible to solve the problem, with having smaller voltage dc dc converter in the inventory, and scattered into higher voltage loads. And that is where one possibility is to have another same identical dc dc converter, and that is also rated for 500 watts name plate. And let us say, it is drawing from the same battery or another battery, for the input and the output is paralleled likewise. So, if load is let us say some 500 watts will it draw if the load here at any given moment or given point of time let us say I will put it as 600 watts.

So, will it draw 300 watts from here and 300 watts from here automatically it is possible, if it is voltage control what could happens is most likely, this will blow in this will also blow. Why it is like now connecting one voltage source in parallel with another voltage source parallel with the load or load. However, observe the issue you cannot t connect two voltage sources in parallel, because always be mismatch voltages and each voltage source try to dominates and as a result there will be circulating currents with in this loop. And this, circulating currents can be very high, because the impedance in the loop is very low ideally 0 and even a very small mismatch in voltage can cause 100s of amps to flow.

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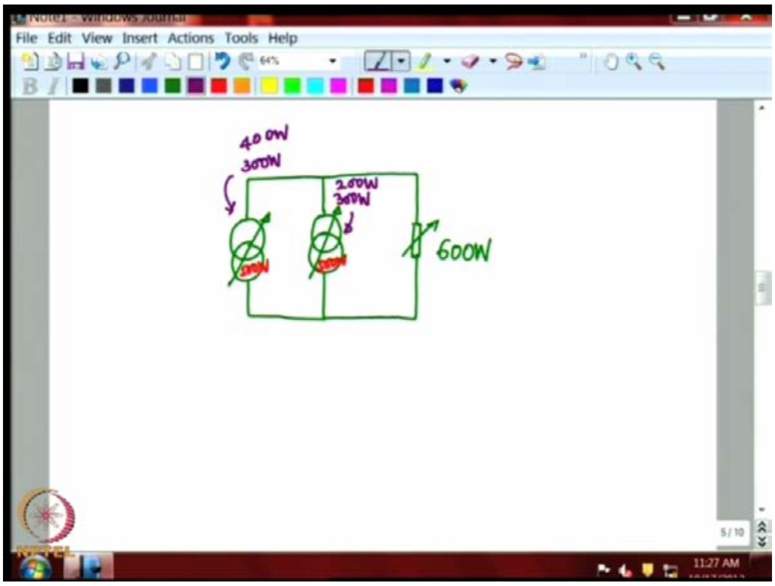

And therefore, blow of both this and this sources, load which is exiting the rating other sources sequence will go back, we need to have a control method where instead of having a controlled voltage source we have controlled current source, so you have current source controlled current sources connected in parallel, because the output current of each of sources are dynamically control. So, even if now let us say this is 500 watts source this is a 500 watts control current source and you are demanding from the load 600 watts. Then you can set to draw 300 watts from this source and 300 watts, 300 watts from this source or you can make it to happen with 400 watts from the source or 200 watts from the source. So, with current control this sort of a strategy is possible, and very advantages when you want to use it for power source for loads, which has power rating much higher than individual current source, this is what try to explore in the next class.

Thank you.