Switched Mode Power Conversion
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Lecture - 8
Issues related to switches

Good day to all of you. In this session we will exclusively devote it for looking at several problems associated with the various kinds of switches that we have studied: The conduction properties, blocking properties, switching properties and the selection of the switch depending on the circuit operating conditions and so on. We have roughly; yeah, we have about 10 problems here, we will go through one by one the problem statement as well as the important issues and how does one go about identifying the critical issues and solving the problems.

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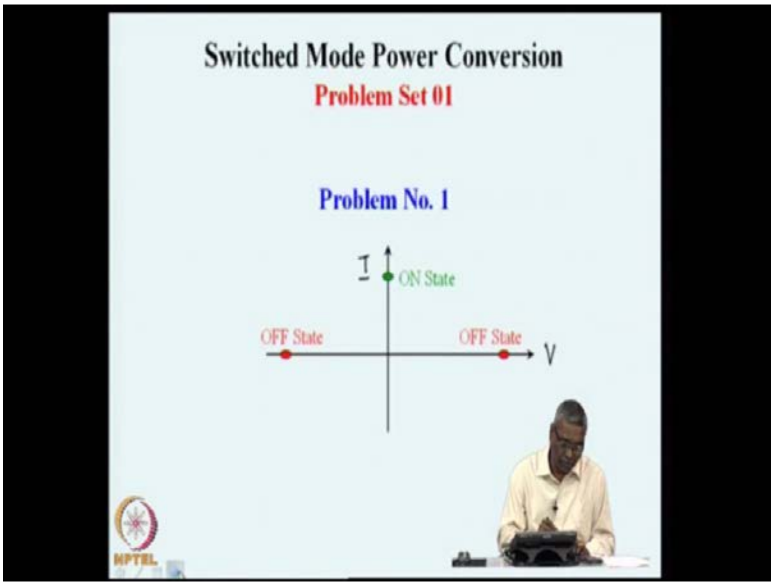

The firsT1 that we see here the V I plane. What you see here is the V I plane, the V and the I plane and on the V I plane several operating points are marked. There are 2 off state operating points: One with a positive voltage off state that is a blocking positive voltage, one with a negative voltage off state a blocking negative voltage and then, a conducting on state where, the conducting current is positive current. Now, the problem is that if you wish to select an electronic switch which is capable of blocking positive voltage, blocking negative voltage and passing positive current, what kind of switch will you select that is the question.

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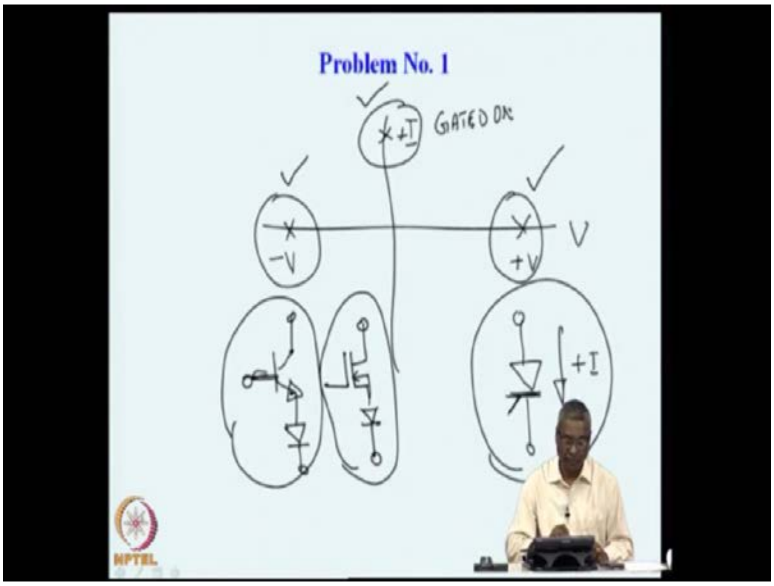

So, we might try to look at these operating conditions. It is necessary to block positive voltage, block negative voltage and then, pass positive current. One possible solution for this is a thyristor which when the gate is turned on it will pass a current which is in the positive direction plus I and if the gate is not enabled on and if we apply a positive voltage to this device it will block positive voltage. And when the gate is not enabled or when the gate is enabled, if we apply a negative voltage to the device then, the device will be in the blocking negative voltage condition. When the gate is on; so, gated condition, gated on; so, the device will pass positive current. So, a device which is a thyristor which has control characteristics through the gate can be selected for this application. It is also possible that we might use a transistor with a series diode so that if the base current is given this device will pass positive current and when the device is not gated on it can pass either positive voltage or negative voltage and this also is a possible candidate and it is also possible in a similar way a MOSFET which has a series diode to do the same function. So, all these switch combinations are capable of meeting these requirements and we would say that a BJT with a series diode, a MOSFET with a series diode or a simple thyristor will satisfy the requirement of blocking positive voltage, blocking negative voltage and passing positive current.

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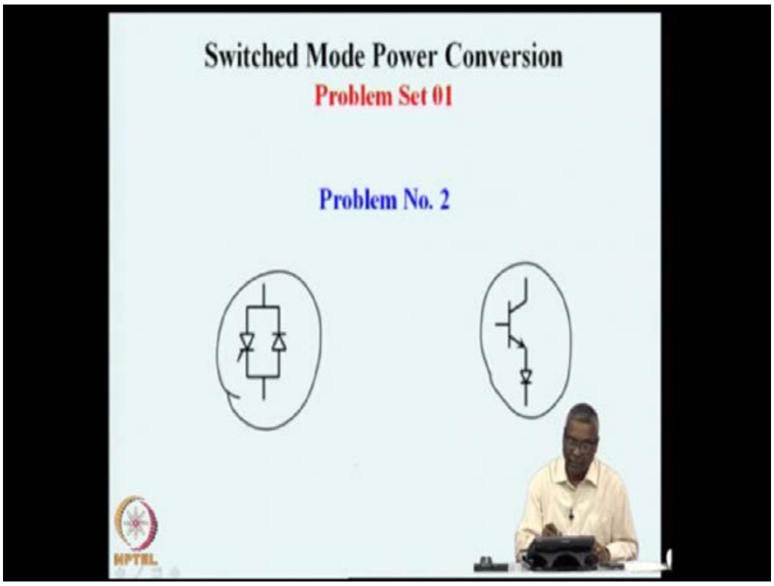

So, let us look at the next problem that we wish to look at. This is the inverse of what we had seen where the devices what you see here, the device is given a thyristor in parallel with a diode or a transistor in series with a diode. Now, we wish to know on the V I plane, what kind of operating points are possible for these combinations of switches.

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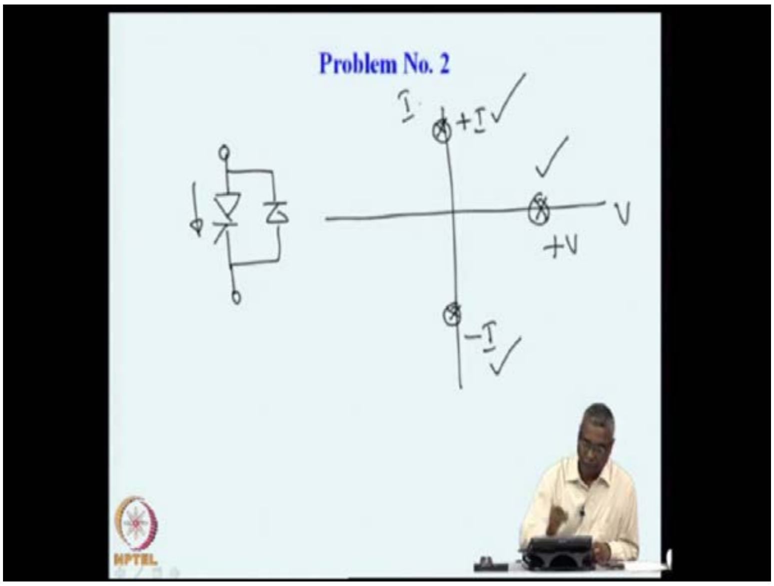

For example, a thyristor in parallel with a diode on account of that diode which is present here, this is capable of carrying current in the positive direction when it is gated on, this is positive I and the devices gated on. And when a negative current is flowing whether, you get it on or not through the diode negative current can flow through this. And when the device is not gated on and if you apply a positive voltage: The thyristor will block and the diode also will block and you can have a plus V blocking, minus I conduction, plus I conduction. And because of diode is being present this device is not capable of blocking negative voltages and a thyristor in parallel with a diode can conduct current in the positive direction, can conduct current in the negative direction, can block voltage in the positive direction. These are the possible operating conditions on the V I plane.

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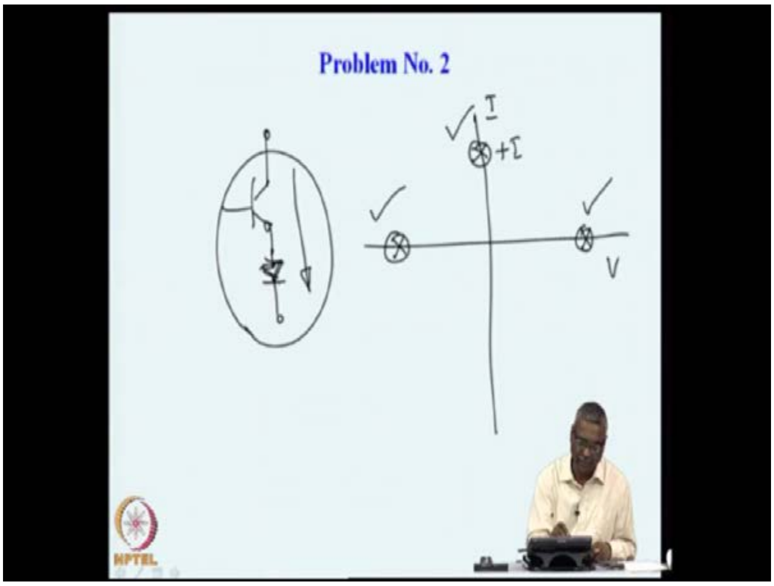

Now, let us look at the other device which is a transistor is in series with the diode. What we have is a transistor which has a series diode. So, we can see that on the V I plane, V I plane the current can be in one direction which is the positive current flowing through the device when the device is gated on. So, when the devices gated off it is possible to block the positive voltage and when the devices gated on or off negative voltage will be block because of the series diode. So, we see that it is possible to block negative voltage, block positive voltage, pass positive current for this combination of device and this would be the operating points on the V I plane for a combination of a BJT in series with a diode.

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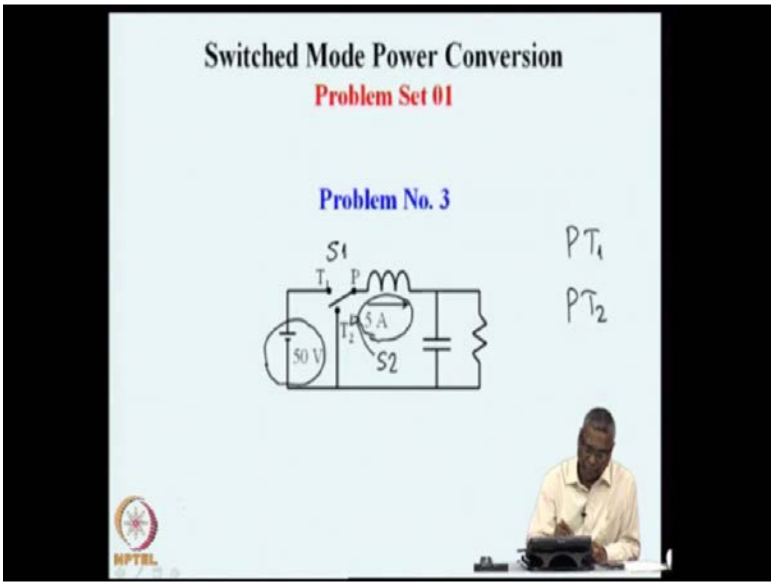

So, let us move on to the next question. So, what we have here is circuit which has 2 switches. What you see here is P1, T1 which is switch 1; and P2, T2 which is switch 2. So, there are 2 switches in this circuit with an inductor, capacitor and a resistor. The operating conditions are that the source voltages 50 volts and the inductor current is 5 amperes. In this particular combination we would like to know, what will be the switch PT 1 and what will be the switch PT 2. This is the question that we would like to answer and the conditions are that the inductor current is 5 amperes nearly study DC in the direction that is shown here and the supply voltage source voltage is 50 volts in the direction that is shown here. Now, let us look at the switch PT 1.

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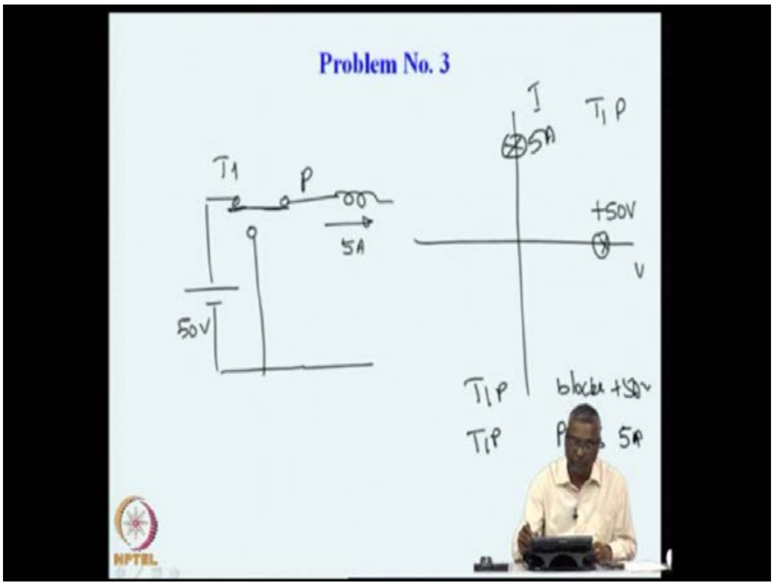

What we have here, this PT 1. This voltage is 50 volts and a current of 5 amperes, current of 5 amperes is flowing through the inductor. So, if you now see PT 1 on the V I characteristics, P is at a voltage of 0 and T 1 is at voltage of positive 50 volts. So, the voltage at T 1, the switch T 1 P has the voltage at P is at 0 and the voltage at T 1 is at 50 volts positive. So, this is plus 50 volts. Now, when the switch is when the switch is now connected to PT 1 is closed, the current flowing through T 1 P is plus 5 amperes which is here, plus 5 amperes. So, the switch T 1 P blocks plus 50 volts and T 1 P passes 5 amperes. The switch is passing positive current and it is blocking positive voltage.

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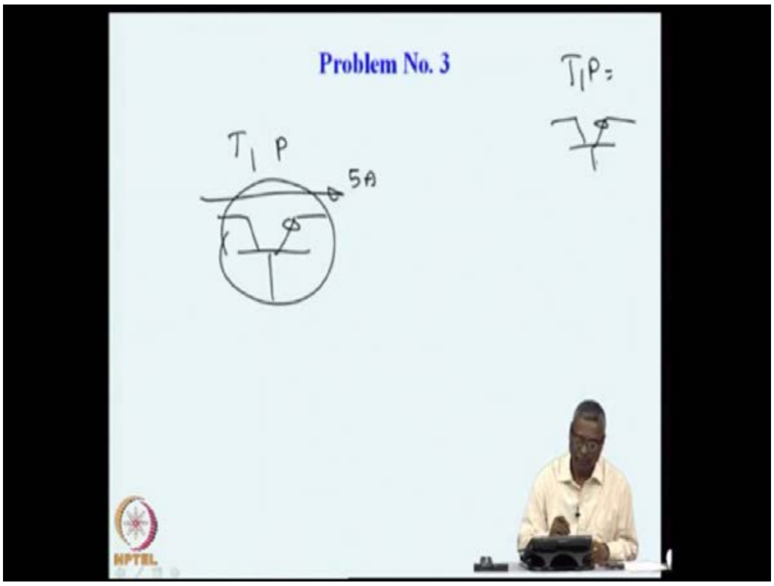

And we can say that, T 1 P is a transistor which blocks positive voltage from T 1 to P when it is gated off and it is passing positive current from T 1 to P when it is gated on 5 amperes. So, we can say that the switch T 1 P is a transistor. So, that is the first. Now, let us go on to find out, what happens to the to the next condition.

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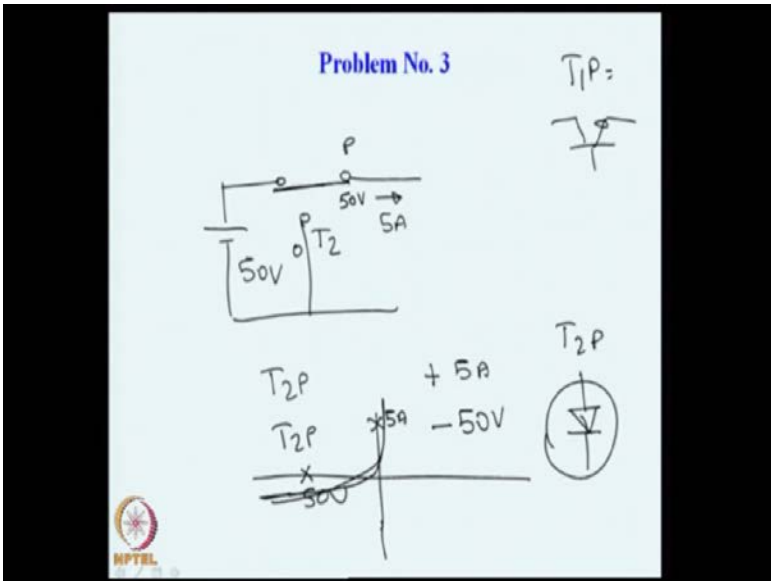

Now, we are looking at the switch which is 50 volts and this is T 2 and this is P; current is 5 amperes. So, T 2 P conducts plus 5 amperes from T 2 to P. And when the switch is off when the switch is off the other switch is conducting. Other switch is conducting at that time the voltage here is 50 volts and the voltage here is 0 volts. So, T 2 P has minus 50 volts that is T 2 is at 0 potential, P is at plus 50 potential. So, what we see here is now, the switch conducts positive current 5 amperes, blocks negative voltage minus 50 volts and such a device is a diode. Diode has a characteristic of this a nature. So, this is what we would call for T 2 P. So, if you now try to put it all together.

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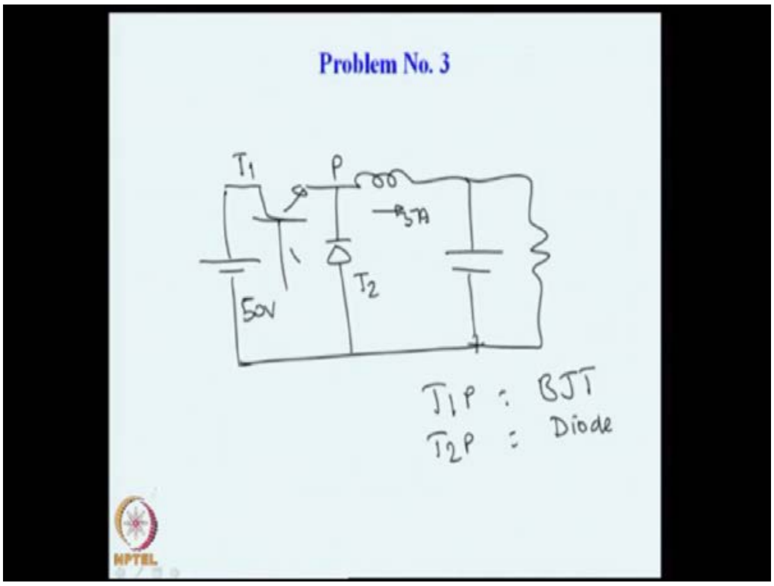

So, you see that the circuit switch has T 1 P is realized by a BJT T 1 P is realized by a BJT transistor and T 2 P is realized by a diode. So, that is how you try to select in any application the switches that are used by electronic devices.

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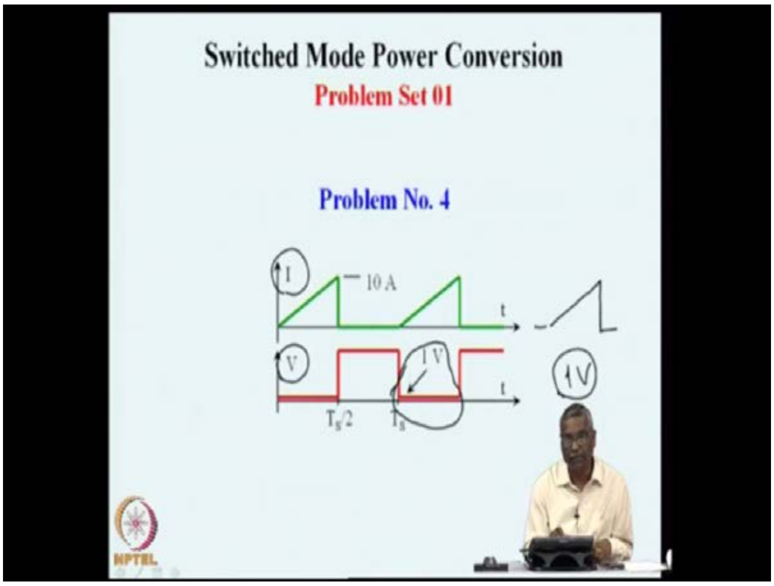

Let us now go to the next problem which is more to do with the losses in the device, the current that is carried, what kind of losses happens while it is conducting and so on. So, what is shown here in this slide is what you see here in this slide is the current through a particular switch and the voltage across the switch in a circuit. When the switch is on, the conduction drop is about 1 volt and when the switch is off, the current carried by the device is about to 0 amperes. During the time the switch is on the current is increasing from 0 to 10 amperes and when the switch is turned off it drops all the way down to 0 ampere. So, we have a triangular current passing through the switch and we would like to know what kind of losses take place in the device.

So, as we see here, during conduction the voltage that is dropping in the device during the conduction is 1 volt 1 volt right and during that time the current that is flowing through the device is a triangular current. So, let us look at how to find out the conduction loss and the on time is T s by 2 and off time is T s by 2, total time is T s. What we see here is for half the time, the device is on and for half the kind devices off.

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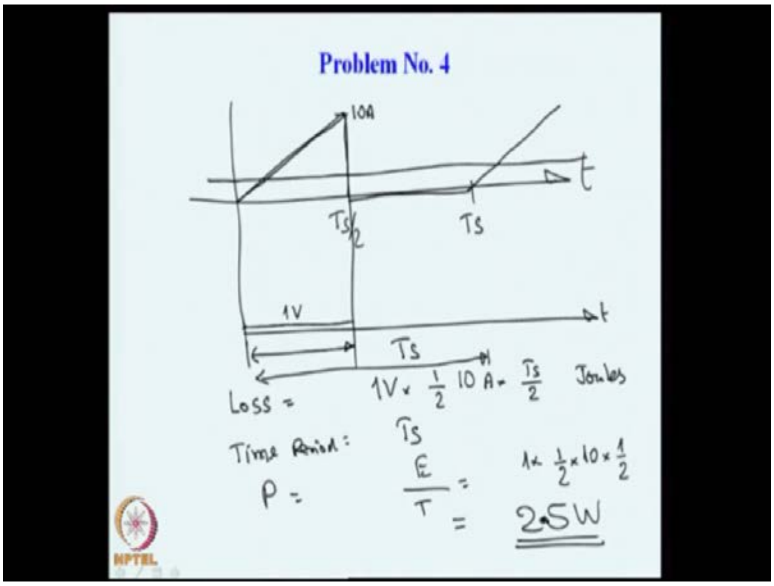

So, if we try to now see the current that is flowing through the device T. So, for half the time T s by 2, the current goes to a peak value of 10 amperes ten amperes and then, the next cycle again is a ramp of that nature. This is T s. So, it is possible to find out the average current of this particular device. So, when the device is on and the voltage across this device is 1 volt and the current is linearly increasing from 0 to 10. So, during this interval the loss is 1 volt multiplied by the average value of this current which is 1 by 2 into 10 ampere. It is linearly increasing from 0 to 10 and this duration is T s by 2. So, this is the total energy loss in joules. And what is the time in which this time period in which this loss is taking place is T s. So, during the next half when the device is not conducting, there are no losses and so, we can say the total period for which this loss is taking place is T s. So, the average power loss is energy loss divided by time and that would be 1 into 1 by 2 into 10 into 1 by 2 and that is 2.5 watts.

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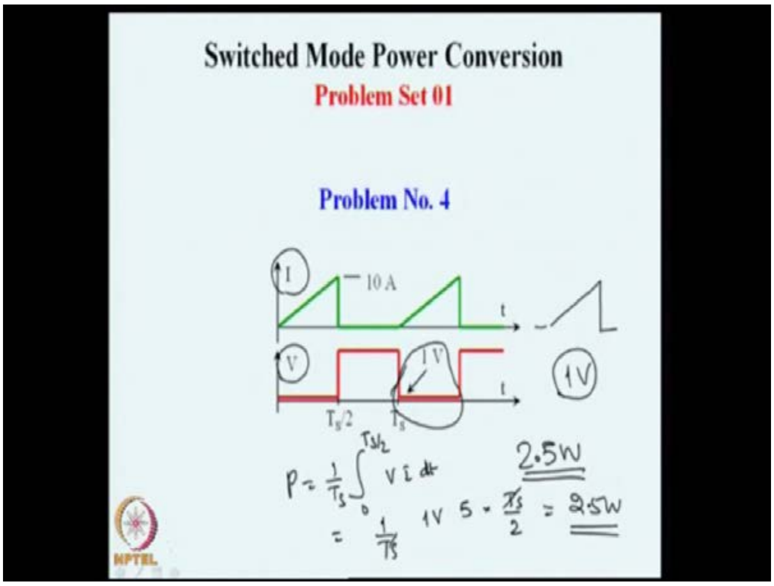

So, the average power loss in this particular application for this circuit, for this application is 2.5 watts and that is conduction loss. So, in order to find out the conduction loss, we find the total energy loss that is taking place in 1 cycle. In this particular example there are no losses during the blocking period. So, find out all the losses that take place in the T s by 2? Energy loss is given by integral of V I d t multiplied by or integral of V I d t in this case because, V is constant the loss is P is integral 1 by T s 0 to T s by 2 V I d t. And this turned out to be 1 by T s, V is constant which is 1 volt and I varies from 0 to 10. So, the average of I will be 5 and over a period of T s by 2 and that comes to 2.5 watts. So, that is how we calculated the power loss.

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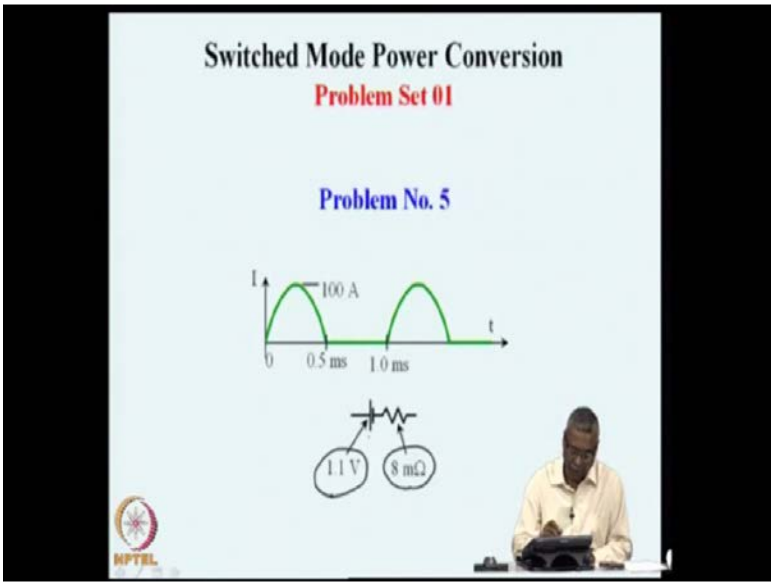

So, let me go to the next step. We have now a slightly more complex waveform for the current to be conducted and the device voltage also is not just a constant voltage, the device is modeled by a voltage drop which is 1.1 volt and a dynamic resistance which is 8 milliohm. And on in this model for the device or through the device with this model we have a sinusoidal current, half sinusoidal current flowing through and the period of that is 1 millisecond, conduction is half the time which is half a millisecond. In this sinusoid half sinusoid has a peak of 100 amperes. So, for such a waveform it is possible to find out the various quantities but, let us write down what the losses are.

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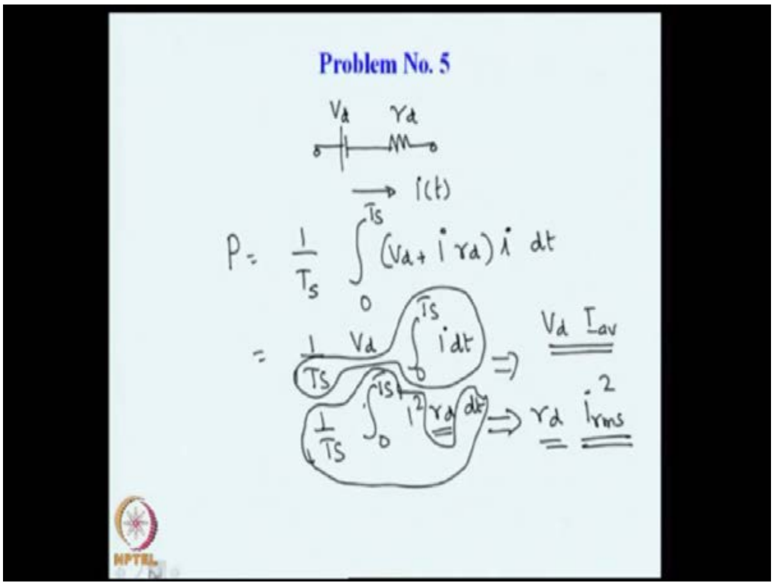

I have in general a device which has a voltage drop and a resistance and it has a current of i of t. This drop I call as V d and this I call as r d. What is the power loss in this? So, we can say that the power loss in this device is 1 by whatever is the period and integral 0 to T s. The total voltage across the terminals which is V d plus i into r d. So, this is the total voltage and that multiplied by i into d t. So, this is the total dissipation that is going to take place. Let us separate this out, this first term will be 1 by T s because V d is a constant term, we will write this as V d into integral 0 to T s i d t is a first term and the second term is 1 by T s i square integral 0 to T s i square r d d t. And this term, first term can be written as V d into i average. Because, if you take V d which is constant outside, this quantity what we see is 1 by T s integral 0 to T s i d t can be simplified as the device drop, the fixed drop multiplied by average current. And the second term can be simplified as r d which is constant quantity multiplied by i rms square. Because the term that we see here, what I have bracketed is i rms square and that multiplied by r d.

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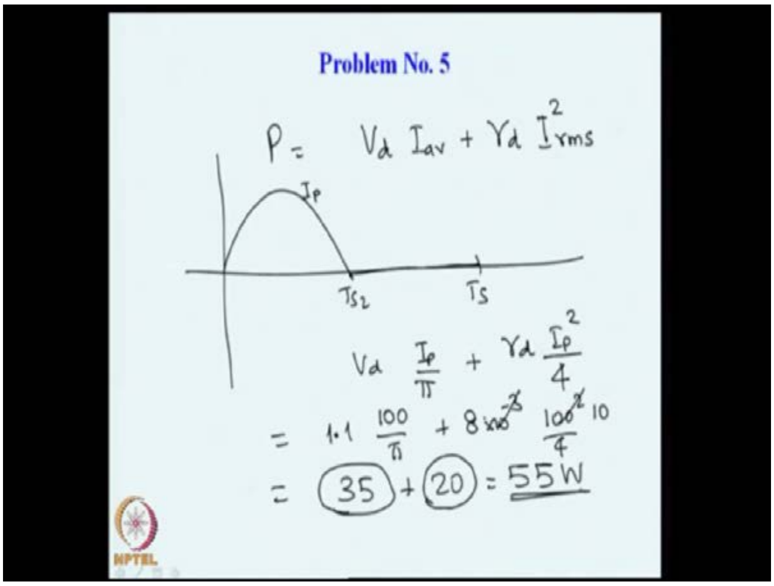

So, in effect in such a model we can simply say that power dissipation is V d into I average plus r d into I square rms. So, for a sinusoidal half sinusoidal voltage T s, T s by 2 and I peak. The average value is nothing but V d into I peak into powerful sine wave. It will be 2 by pie and for this it will be 1 by pie; so, this is the first part. And the second part will be r d into for a full sine wave rms will I p by route 2, for a half rms it will be I p square divided by. Because, half sinusoid has an rms value which is just I p divided by 2; this will be I p square by 4. And in our application, V d is 1.1 and I p is 100 divided by pie plus r d is given as 8 milliohm, 8 milliohm multiplied by I p square which is 100 square divided by 4 and if I calculate this, the first part will be 110 divided by pie which is 35 watts plus 100 square into 10 power minus 3 will be 10, 80 by 4 is 20 watts that will turn out to be 55 watts. So, this portion is because of the average current dissipating power in V d, this is the rms current dissipating power in r d and the total power dissipation is 55 watts.

Let us move on to the next problem.

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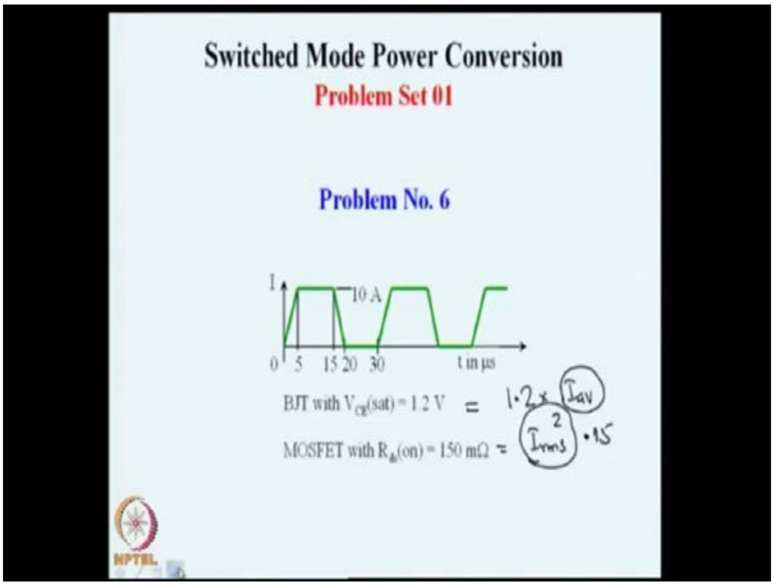

This is again a very similar question but, in this we have a current waveform which is a trapezoidal shape, what you see here is a trapezoidal shape of current. The time is shown in microseconds in the x axis, current is shown as 10 amperes as the flat peak and a rising time of 5 microseconds and a falling time of 5 microseconds. The question is for this particular application what will be the loss if the device used is a BJT with a constant voltage or a MOSFET with a R ds on of 150 milliohm. We had seen in the earlier case that the power dissipation depends on average voltage, average current multiplied by voltage drop or R ds on multiplied by square of the rms current. So, in this particular example, we will see that 1.2 multiplied by I average will be the power loss. And in the second case if we have chosen a MOSFET, the rms current of this multiplied by 0.15 will be the power loss. So, what we have do is, for this particular waveform we must find out rms average current and also the rms current square and then, after evaluating that find out what the total losses are. So, let us do that.

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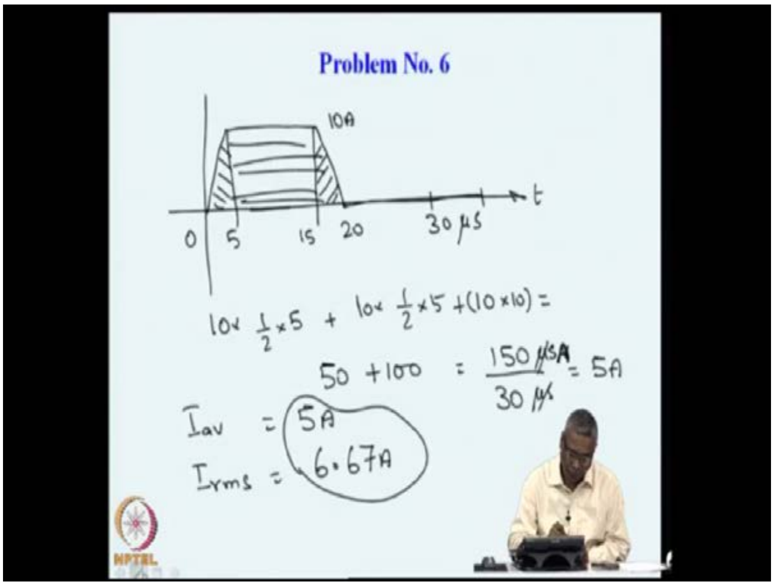

So, for this particular waveform; I have a trapezoidal waveform. This is 0, 5, 15, 20 and the end of the period is 30 microsecond. The average voltage is this total area divided by 30 microseconds. So, this area of this part is 10 into 1 by 2 into 5 that is area of the triangle half base into height. Similarly, there will be one more such area here, plus 10 into 1 by 2 into 5 which is this part and then, plus I will have 10 into 10 which is this portion. So, if I had all these area, this would be 50 plus 5 into 10 by 2, 5 into 10 by 2 total 50 plus 100 which is 150 units divided by microsecond 30 microseconds. So, this is micro into volt microsecond into volt is this area and this is microsecond. So, what you will get will be ampere microsecond into ampere. So, what you get will be 150 by 30 which is 5 amperes. So, we can say that for this waveform I average is 5 amperes. So, in the same way it is possible to calculate the rms for this waveform and that turns out to be 6.67 amperes. In this particular example we will kick these numbers alone, average and rms. Let rest of it can be cleaned.

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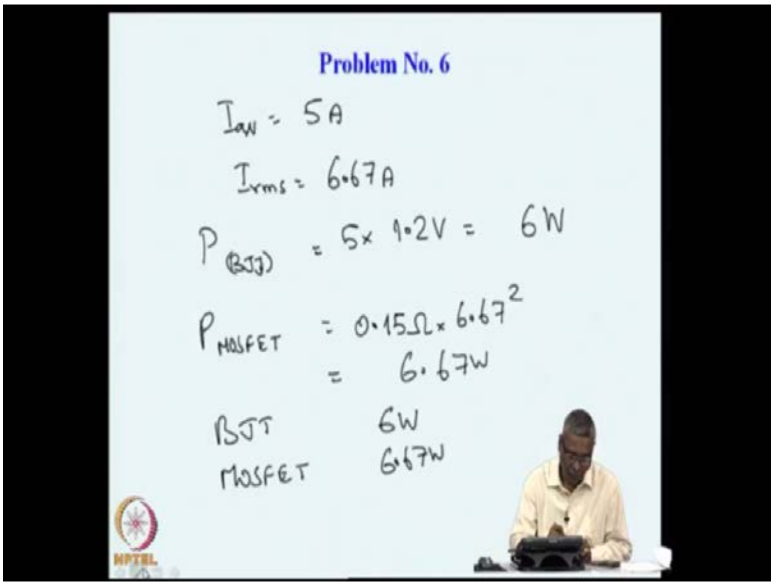

So, I have, I average is 5 amperes and I rms is 6.67 amperes. So, it is possible to find out the loss of a BJT that will be 5 into voltage drop which is 1.2 volts which is 6 watts. As we know that the power loss is average current multiplied by the device voltage drop which is constant in a BJT. And if it is a MOSFET, MOSFET is represented as a resistance whose value in this particular case is 0.15 ohm and multiplied by 6.67 square. So, this 0.15 into 6.67 whole squares multiplied by the 0.15 which is 6.67 watts. So, we see that BJT dissipate 6 watts for this application. MOSFET dissipate 6.67 watts for this application. Both are merely equal but, BJT is slightly more efficient having less loss.

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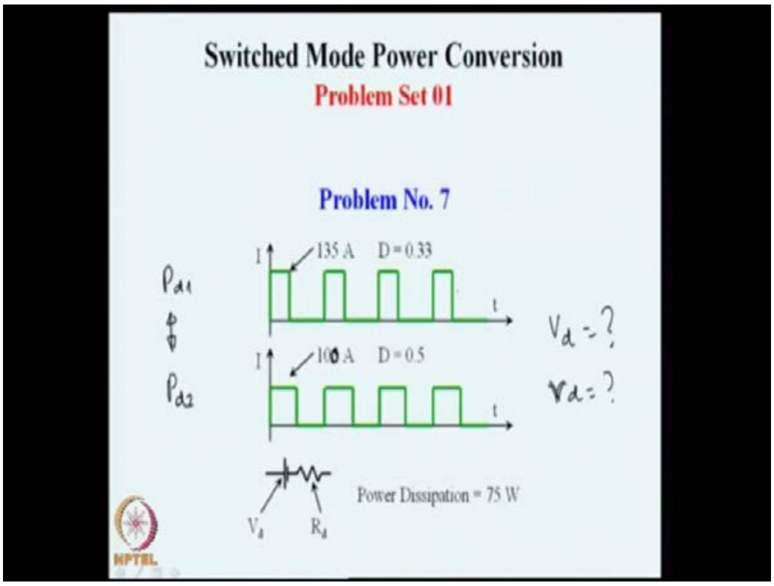

So, let us go to the next problem. This is a slight variation of the same condition. We have a power device which has 2 different ratings which are given to us, this is 100 amperes. For a duty ratio of 0.33, it has a power dissipation of 135 amperes and for a dissipation of 0.5, the power dissipation is current maximum current is 100 amperes but, the device power dissipation is constant and that is given as 75 watts. So, the question is, what is V d and what is r d? This particular example, given the data that the device is capable of having a peak current of 135 amperes for a 0.33 duty ratio application and a peak current of 100 amperes for a duty ratio 0.5 application and if the device is modeled with a constant voltage V d and a dynamic resistance r d, what will be these values if the device power dissipation is constant and equal to 75 watts? This problem can be seen as the power dissipation in the case one and power dissipation in case two have to be equal but, then the peak current and duty ratios are different. So, we can formulate those power dissipations.

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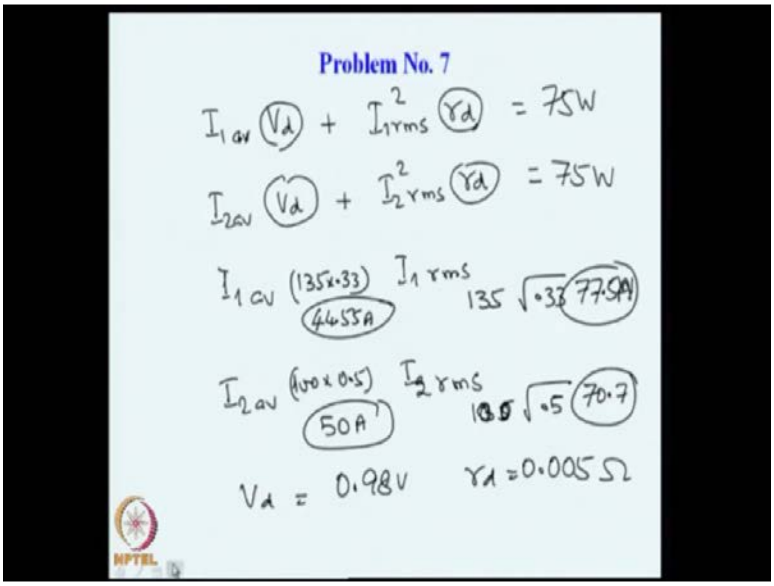

That case one: I 1 average, I 1 average into V d plus I 1 rms into r d, I 1 rms square into r d this is equal to 75 watts. Case two is I 2 average into V d plus I 2 square rms into r d is also equal to 75 watts. So, this is the formulation of the problem. We do not know V d, we do not know r d and all other quantities are known. I 1 average and I 1 rms, I 2 average, I 2 rms are known to us.

How do we know that? We can say that, I 1 average and is 135 average is peak into duty ratio which is 135 multiplied by 0.33 I 2 average is 100 into 0.5. So, this is 50 amperes and this is 0.33 into 135 which is 44.55 amperes. I 1 rms is 135 into route of 0.33 because it is a square wave application with the duty ratio 0.3, you can cross check this. And second case will be 135 into route of 0.5 and these numbers are 70.7 amperes, I 1 rms 135 into route of 0.33 is 77.5 amperes. And the second case is 135 multiplied by route of 0.5, I 2 is 100 into route of 0.5 so, that is 70.7. So, if all this currents are known to us average and rms. So, if we plug it in which this equation with 2 variables 2 equations with 2 variables and V d the can be calculated to be 0.98 volt and r d can be calculated to be 0.005 ohm. So, in such applications if we know the power dissipation and the operating conditions of 2 different situations, it is possible to separate the model parameters of voltage drop and dynamic resistance.

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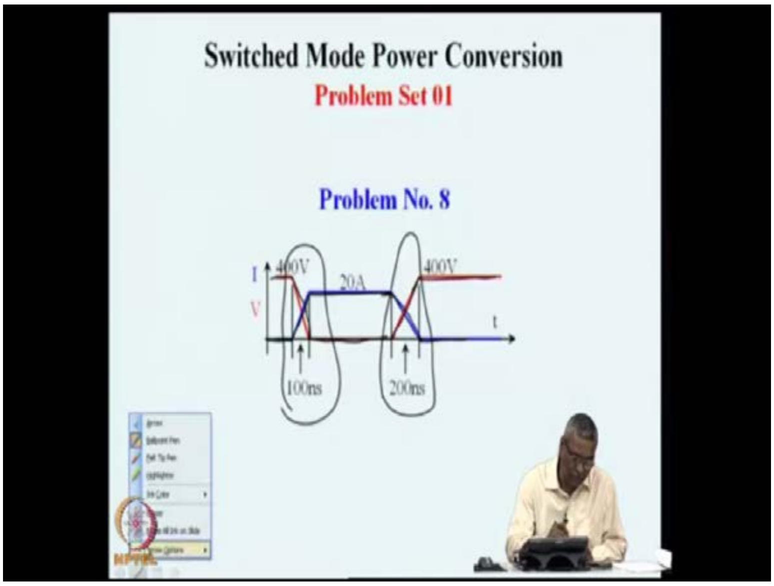

So, let us look at another problem which has to do with dynamic conditions. So, what we see here in this problem is the voltage across a switch and the current through a switch for a full cycle. You see that, the voltage starts with 400 volts and when the device turns on, the voltage drops down all the way to the voltage drops down all the way to 0 and then, when the device off, it jumps back to 400 volts. And correspondingly, when the device turns on, current goes to 220 amperes and then, when the device turns off, current drops to 0 ampere. So, our issue now or our concerned now is to find out what is the energy loss during this period and what is energy loss during this period. During the turn on time when the voltage is dropping from 400 to 0 and current is rising from 0 to 20. And in a similar way, when the current is dropping and the voltage rising; what are the total losses in the device? So, let us see how this is to be done.

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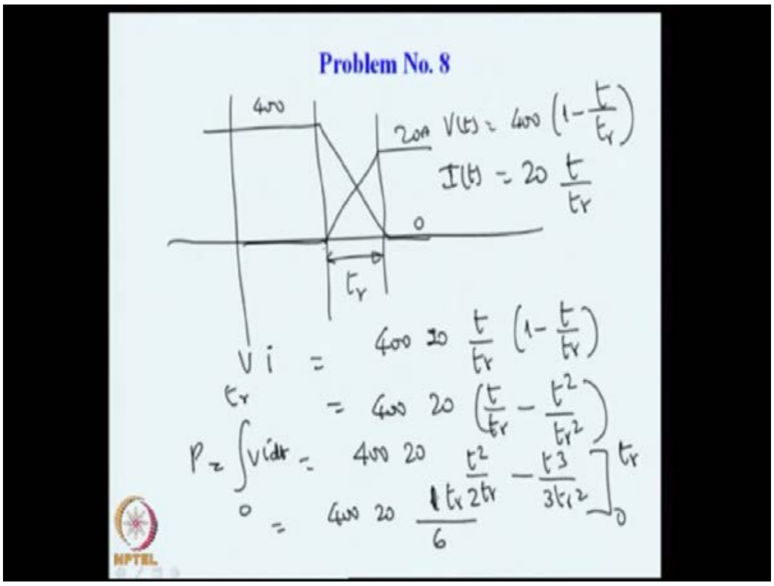

So, we can see that in one particular situation where the voltage is dropping from 400 to 0 in a time of t rise time. The voltage can be written as 400 into 1 minus t by t r. This is the between this interval the voltage follows this equation of 400 multiplied by 1 minus t by t r. During the same time current is rising from 0 to 20 and the current can be written as I t 20 into t by t r. So, power dissipation instantaneous power dissipation is V into i that is 400 into 20 into t by t r multiplied by 1 minus t by t r and this is 400 into 20 into t by t r minus t square by t r square. And if we now power dissipation is integral if V i d t from 0 to t r can be written as 400 into 20 which are constants. And integrating the first term will give you t square by 2 t r, second term will give you t q by 3 t r square; calculate from 0 to t r? So, this will be 400 into 20 and into 1 by 2 minus 1 by 3. Because, when you substitute the value t r this will become t r by 2 and this will become t r by 3. So, 1 by 2 minus 1 by 3 will be 1 by 6 into 1 into t r.

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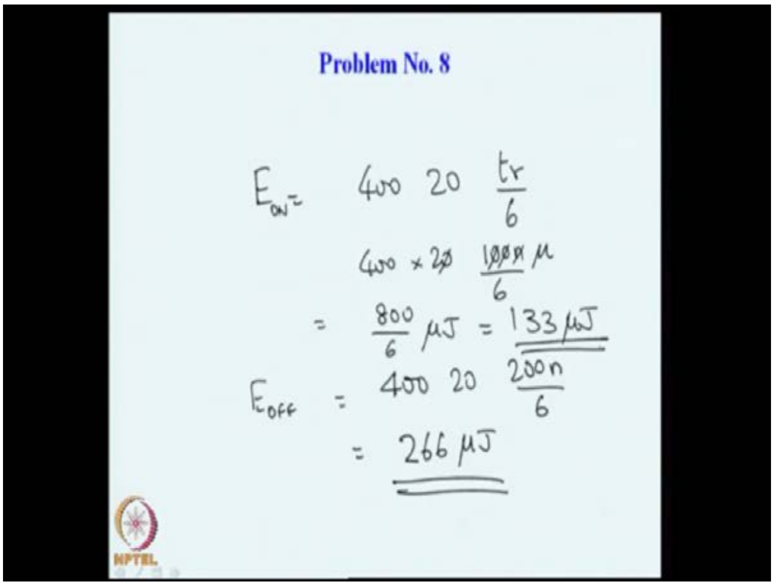

So, our total power dissipation can be written as power dissipation or energy dissipation, energy dissipation is 400 20 t r by 6. In this application t r is given as, go back. t r is given as 100 nanoseconds. So, the losses are 400 into 20 into 100 nano divided by 6 which is so, nano 1, 2, 3 into nano will become micro. So, 400 into 2, 800 divided by 6 microjoule and 800 by 6 about 133 microjoule. And in the other, this is the turn on energy loss. If you calculate the turn off energy loss that is also 400 into 20 but, it is now t f by 6 which is 200 nanoseconds. So, this whole thing will be 200 nano divided by 6 will be double of this 266 microjoule.

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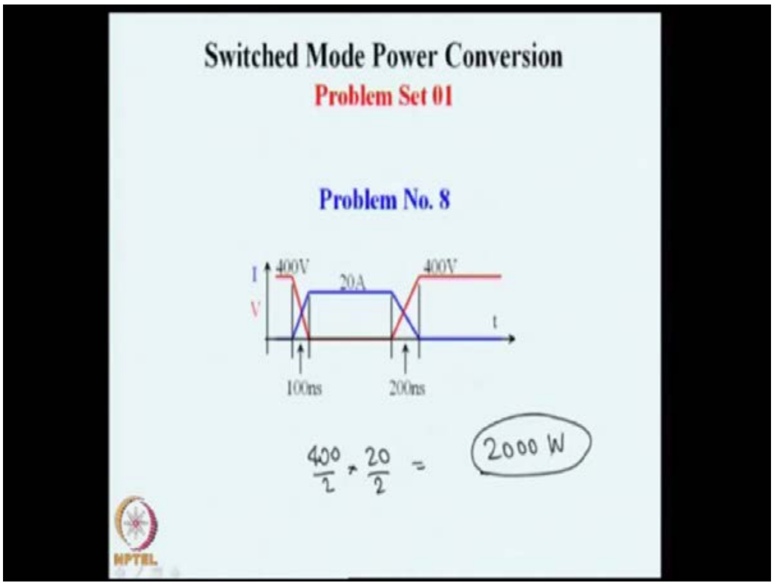

So, the important point to be seen is that when the voltage is falling linearly and the current is also falling linearly, the power dissipation peak power dissipation occurs somewhere in the middle of this and that peak power is 400 by 2 multiplied by 20 by 2 is 400 into 20 divided by 4 that is, roughly 2000 watts. This is the peak power dissipation. Both during on time and off time, the peak power dissipation occurs exactly in the middle and that is 2 kilo watt.

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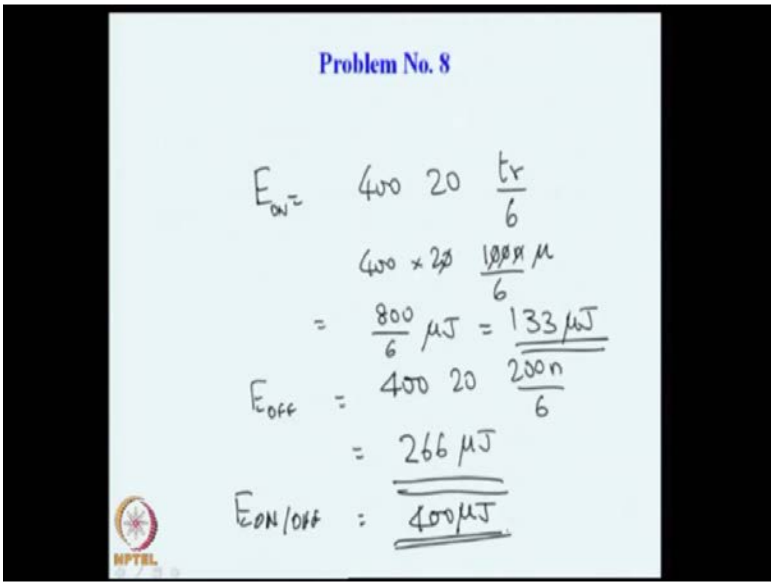

But, the energy dissipation is 133 microjoule during the on transition and 266 microjoule during the off transition. And one on off transition that is, one switching cycle will have the sum of these two, which is roughly 400 microjoule. So, this is the power dissipation per switching cycle because of the switching process. So, let us go on to the next problem.

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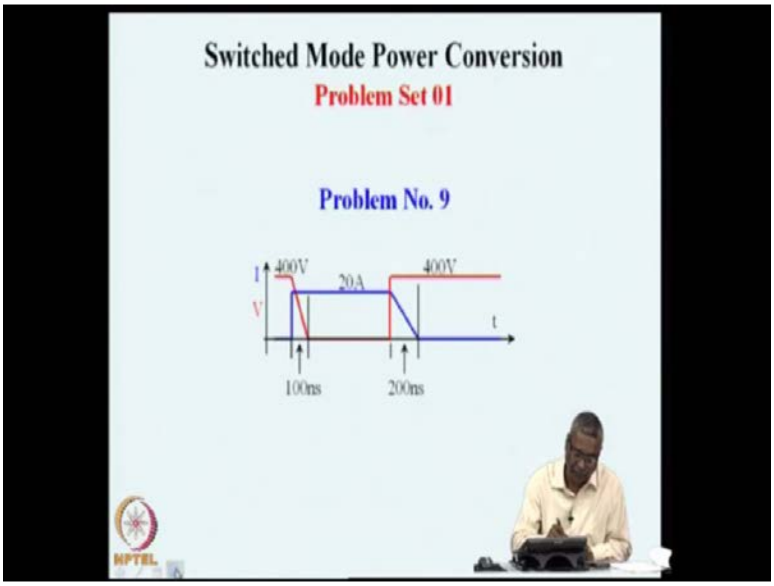

This is a very similar situation where, the switching is not a resistive load but, an inductive load. So, in this particular example what you notice is that, when the voltage is dropping, when the device is turning on, voltage linearly drops to 0 in time 100 nanosecond. But, the current instantly jumps to 20 amperes. Similarly, during the turn off interval, current linearly drops from 20 to 0 in 200 nanoseconds but, the voltage increases instantly to 400 volts. What will be the power dissipation in this case where the load is inductive?

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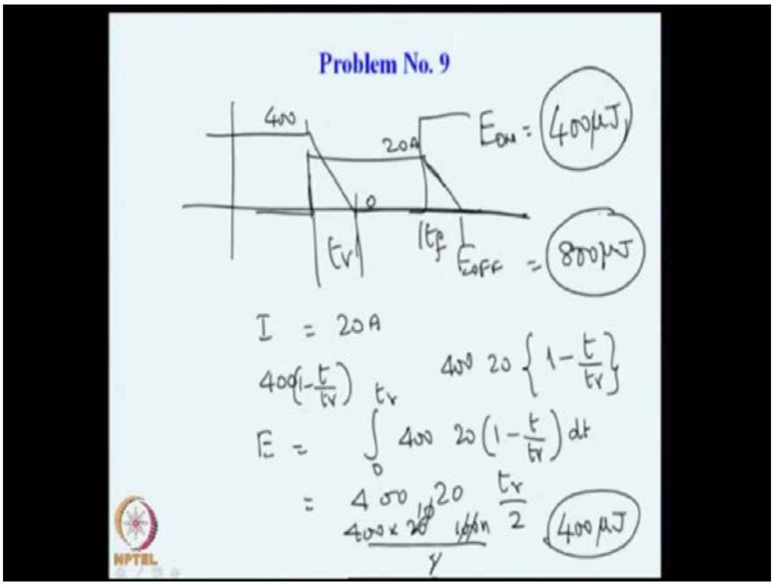

So, we can see that now the one of them the voltage drops linearly during turn on from 400 to 0. But, the current rises instantly from 0 to 20 amperes. So, the calculation is much simpler here because during the entire t r interval from 0 to t r, current is constant which is 20 amperes and the voltage is varying 400 into t by into 1 minus t by t r. So, that is how the voltage is dropping. So, the power instantaneous power dissipation is 400 into 20 multiplied by 1 minus t by t r and the energy dissipation is integral 0 to t r 400 into 20 into 1 minus t by t r d t. So, this is the energy loss during this transitions and this can be proved to be 400 into 20 into t r by 2. Because the current voltage is dropping linearly, you can say that 400 by 2, constant current 20 and duration t r. And this t r is 100 nanoseconds for our case. So, 400 into 20 into 100 nano divided by 2 this becomes 10 and 1 2 3 that is micro. So, we have 400 microjoule. So, in comparison with a resistive load inductive load results in higher loss. We saw that with a resistive load this loss was 133 microjoule but, now the loss is 400 microjoule. Inductive loads resulting higher loss because of the instantaneous change in current. In the same way, when the current is dropping linearly and voltage is jumping instantly, we will find that E OFF will be, this example 800 microjoule double of this because all other things same. The fall time is a 200 nanosecond as we had seen; 200 nanosecond. So, you see that the energy during turn on loss is 400 microjoule and turn off loss is 800 microjoule.

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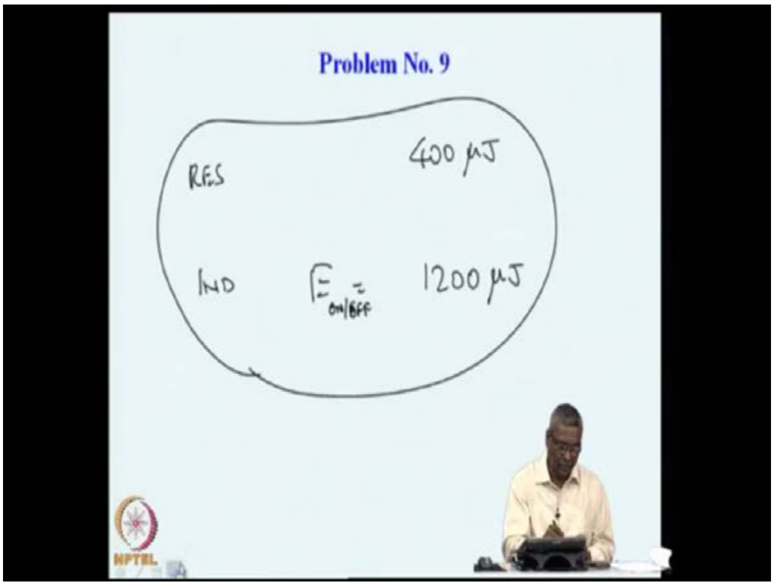

And so, we can say that the total power loss is 1200 microjoule on to off. This is inductive. And if the same thing was resistive, we saw that this was only 400 microjoule. That was a previous example that we had seen.

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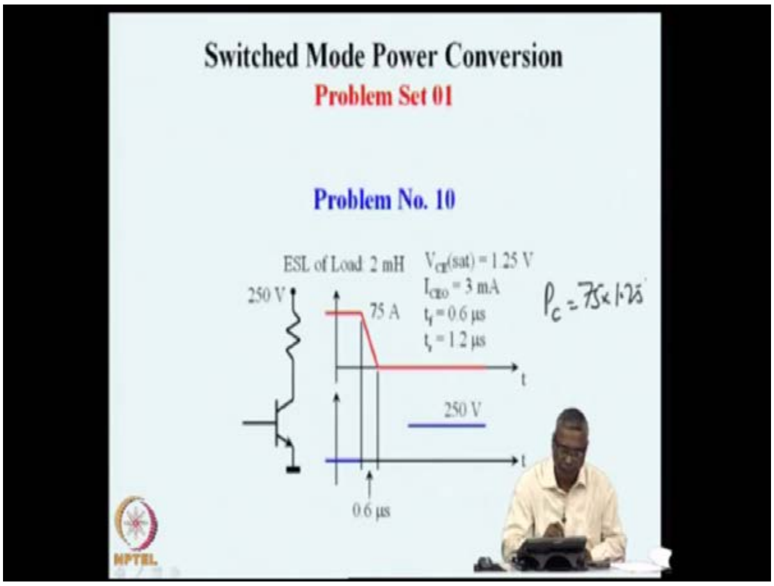

So, let us see the next question. This is a case where, a transistor is switching on and off a resistive load. The saturation voltage when the transistor is on is 1.25 volts and when the switch is on the conduction is 75 amperes. So, let us find out, what is the conduction power loss? It is 75 into 1.25.

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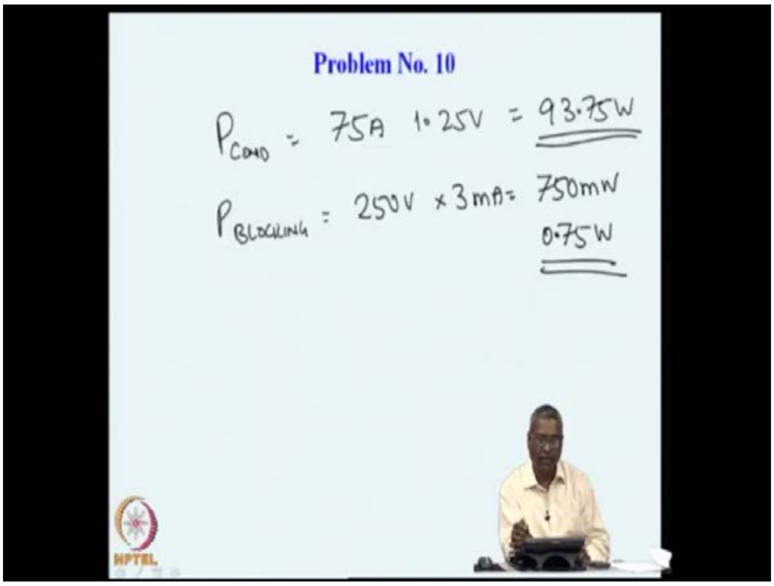

Or if we go, we can say that P conduction is 75 amperes into 1.25 volts and this number is 75 into 1.25 is 93.75 watts. So, let us see what is the blocking loss? Blocking loss is when the device is off there is a leakage current of 3 milliamperes, what you see here; leakage current of 3 milliamperes and the device is blocking 250 volts. So, we can say that blocking loss is 250 volt into 3 milliamperes which is 750 milliwatt or 0.75 watts.

So, you can see that in comparison with conduction loss, blocking loss is orders of magnitude smaller, almost 100 times smaller. This will always be true in most of the switches that when the device is off it is closer to the deal. That is, the blocking non-ideality which is a leakage current is an extremely small dissipative loss is the consequence of the blocking part. But, the conduction part results in 1.25 volts drop instead of 0 and that results in a conduction loss which is 93 points or 94 watts approximately. So, between the 2 losses conduction loss and blocking loss, you can see that the conduction loss is much higher 100 times more than blocking loss. And normally, blocking losses are completely negligible in most applications. We will not even calculate them because we know that for most devices if you calculate conduction loss the blocking loss is going to be extremely small fraction of the conduction loss. So, let us look at one more issue related to this particular problem. Come back to back.

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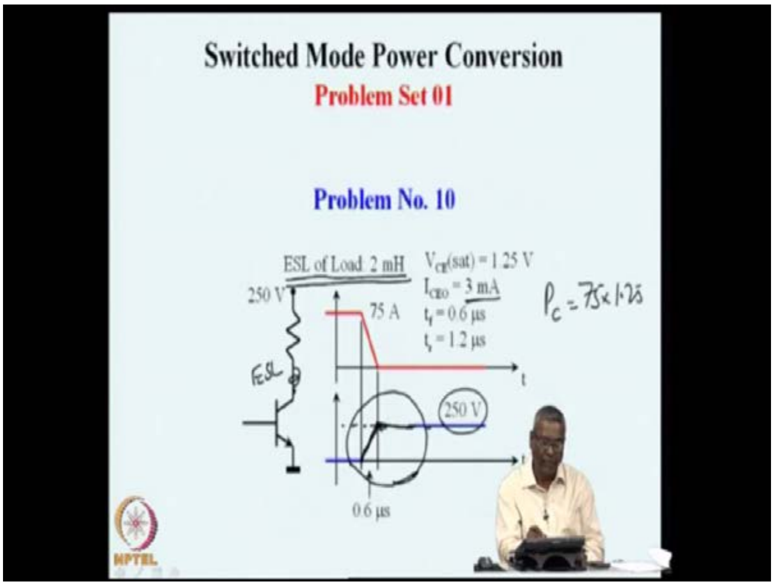

Another issue that we would like to see is, this resistance is not a pure resistance but, it has an equivalent series inductance of 2 millihenry. What is the consequence of that on the voltage that is going to appears across the device when the device turns on? If this resistor is a pure resistor this voltage will follow a straight line and reach 250 volts. So, what we see here is that, if this resistance is a pure resister, this voltage will simply reach 250 volts at the time when you are starting to switch off the current is 75 amperes, voltage is 0. As the current is dropping the drop across this resistance now is the current whatever is the instantaneous current into this resistance which is going to be smaller than 250. So, what is reduced from the supply voltage, we drop this I r drop. So, at the end of this time when the current comes to 0 the voltage here will be the same as 250 volts and that is what we see. But, there is an important difference here the inductance or the resistance has an equal at series inductance. In such a situation, what will happen to the voltage across the device when it switches off? Is the question that we want to answer.

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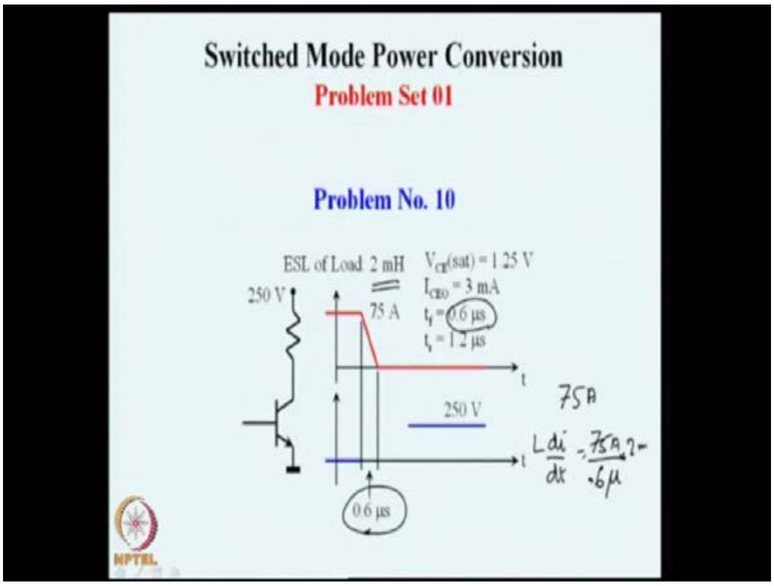

The duration is, this duration is 0.6 microsecond and the current that is dropping is 75 amperes. So, you can see that during this time there is a d i by d t experience and the L is 2 millihenry. So, we can say that during that time this L d i by d t is 75 ampere is d i, time is 0.6 micro 0.6 micro and then, L is 2 milli.

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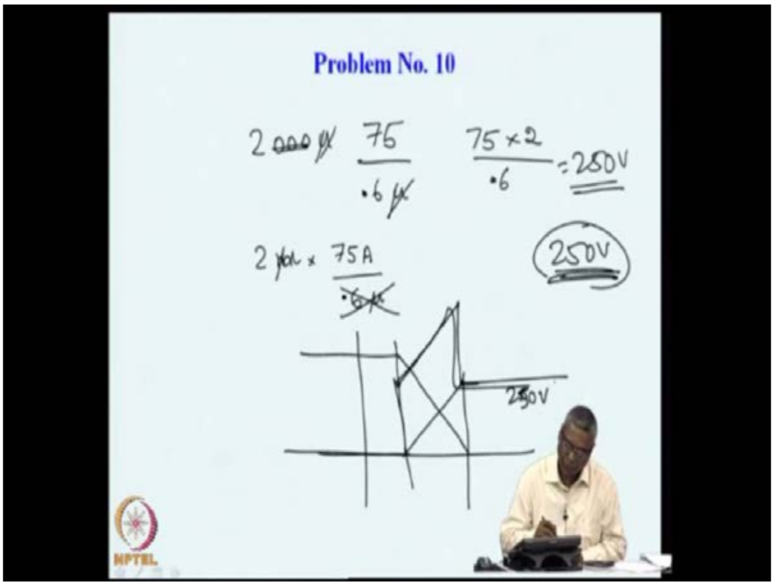

So, this can be written down as, the device drop is 2 milli which can be written as 2000 micro and voltage current drop is 75 in a time of 0.6 micro. Micro is micro is gone. 2 millihenry 0.6 microseconds; sorry, 2 millihenry L into d i by d t. So, let me see, what is that voltage? 75 amperes 0.6 micro. L this 2 millihenry into 75 amperes divided by 0.6 micro. I think this has to be 2 microhenry 2 micro henry. And yeah, I think in this particular problem what we have seen here and this is 2 microhenry. So, then L d i by d t is 2 micro by 0.6 will be 75 into 2 divided by 0.6 that is 250 volts. So, the voltage across the inductor; we will cleanup almost things. Yeah, 250 volts is our device voltage drop. So, we can now we see that when the current is dropping, we will have a voltage drop voltage rise which is 0 to 250 on that we have to have at every point 250 volts added. And so, this voltage will go to 250 and then, that all this points, what we see here.

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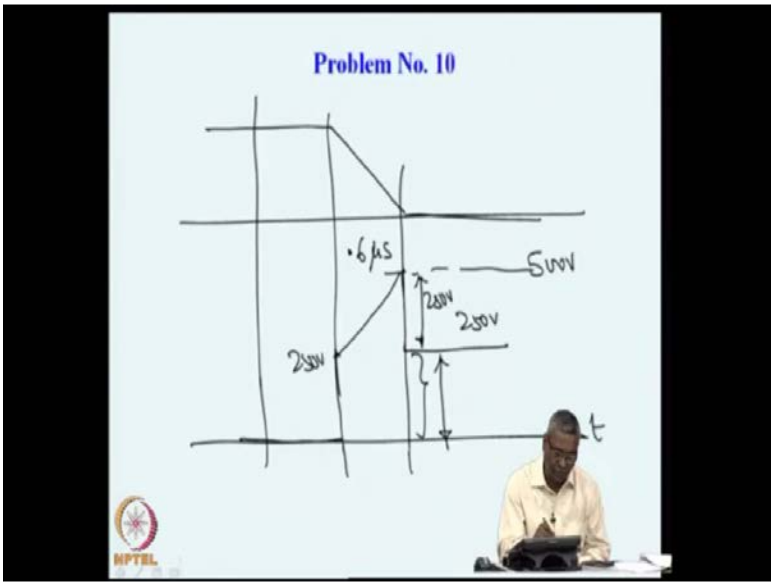

So, just before turning of just before completely turning of, the voltage goes to the peak of 500 volts which is the resistor drop plus the inductive drop. The supply voltage plus the inductive drop and that is what we had seen in this particular example.

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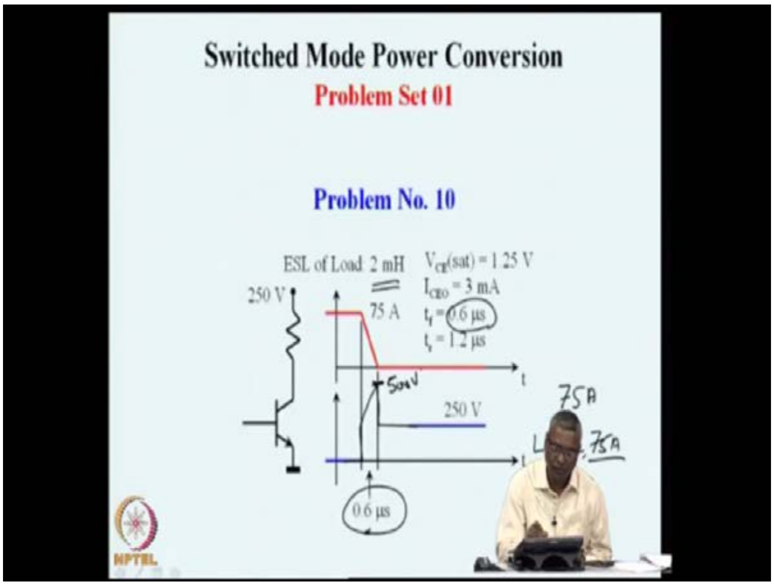

So, what we notice is that, in this example the voltage jumps off to that nature, additional voltage of 500 volts at this point.

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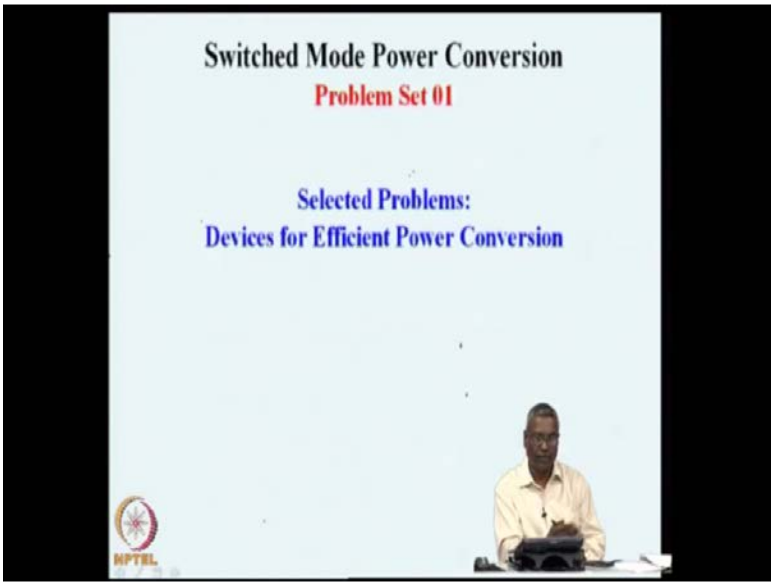

So, what we had seen in this particular session is about 10 problems relating to different aspects of switches, conduction loss, switching loss, calculation of power loss, calculation of peak power loss, energy loss and so on. And we will probably have one more session where we will look at other devices like inductors and capacitors; look at some of the problems associated with those devices and after that session is over will be able to get on to the power converter circuits as such.

Thank you very much.