Switched Mode Power Conversion
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Lecture - 38
Unity Power Factor Converter

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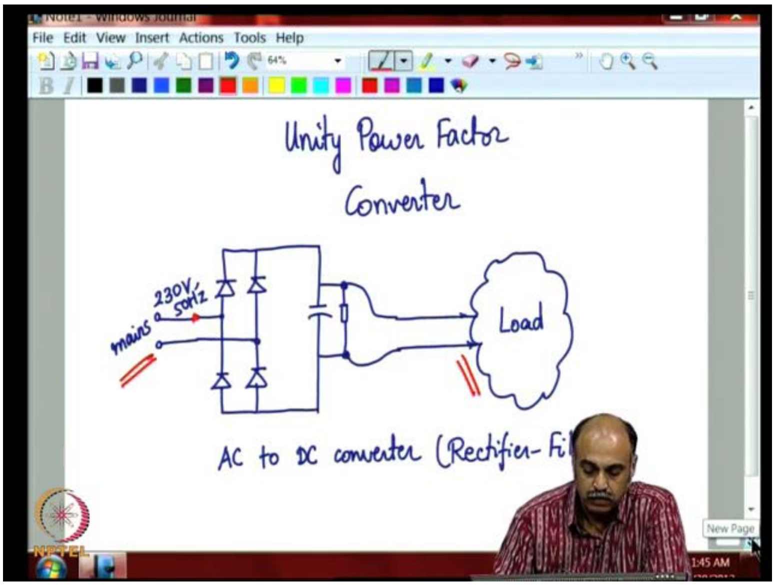

Good day to all of you, so today we shall take up the topic of, unity power factor converter unity power. Let, me first give you the background to this topic and then we will go about seeing, how we go about developing DC DC converter, which will address this problem. So, most of the electronic equipments loads, so I am going to use this as a load symbol to the loads, we normally use rectifier and combine it with the capacitor filter circuit like this. This is followed by the capacitor and may be a leaded resistance and goes to further loads.

This is the most popular Ac to Dc converter or plainly rectifier filter circuit, that is used in most of the front ends of the electronic equipments. Here, we have the 230 volts 50 hertz, 230 volt rms 50 hertz in in our country. Few other countries, we would have 150 volts 60 hertz, so those standards are also there. So, this is basically coming from the mains, now if you take these particular circuits, which is interfacing on the one hand means, to the load on the other hand. It is interesting to see the current at this point, what is the current, which is drawn from the mains?

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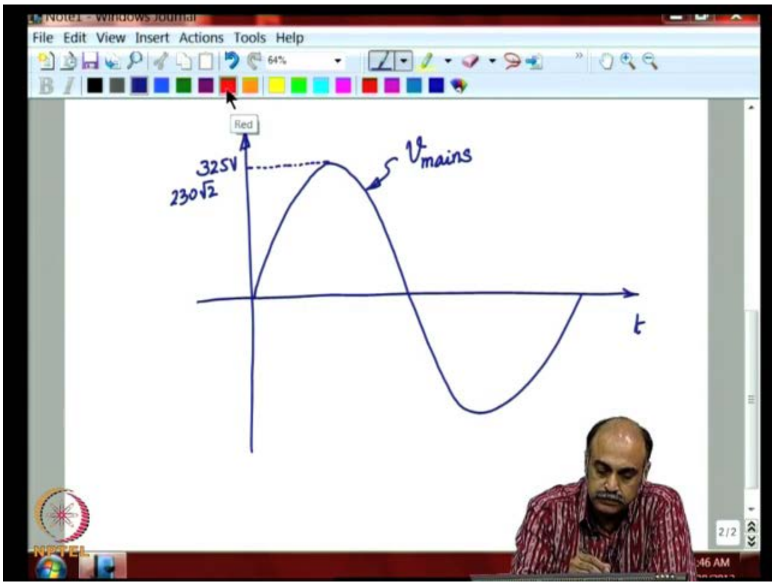

So, if we try to draw the current; that is taken from the mains. Let us say in a cycle, lets this is the main voltage waveform sinusoidal one period, this is v mains. So, for a 230 volt rms this will be around 325 volts, basically 230 root 2.

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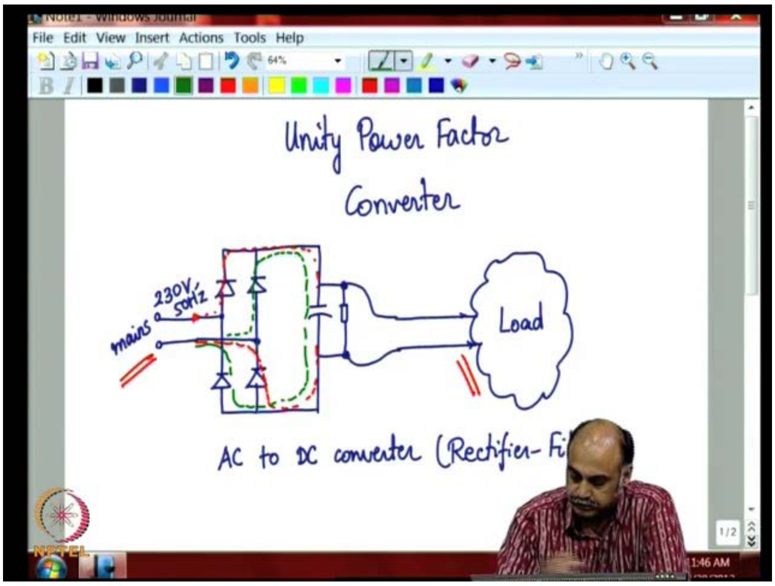

Now, the current of a capacitor filter rectifier circuit is basically, this diode current, which would float through this during one of the cycle and it would go through this diode during the other half of the cycle.

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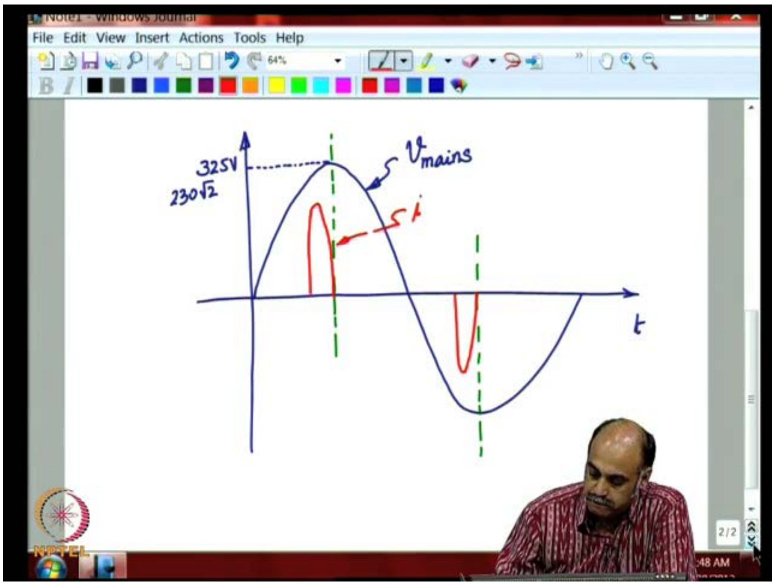

Now, if you analyze the shape of the waveform, it is something like this. Now, let us identify the peak and just before the peak, you will have a shoot coming down that and likewise here. So, this would be the current waveform, which you would see here at the mains. Now, let us say because of this, what are the issues?

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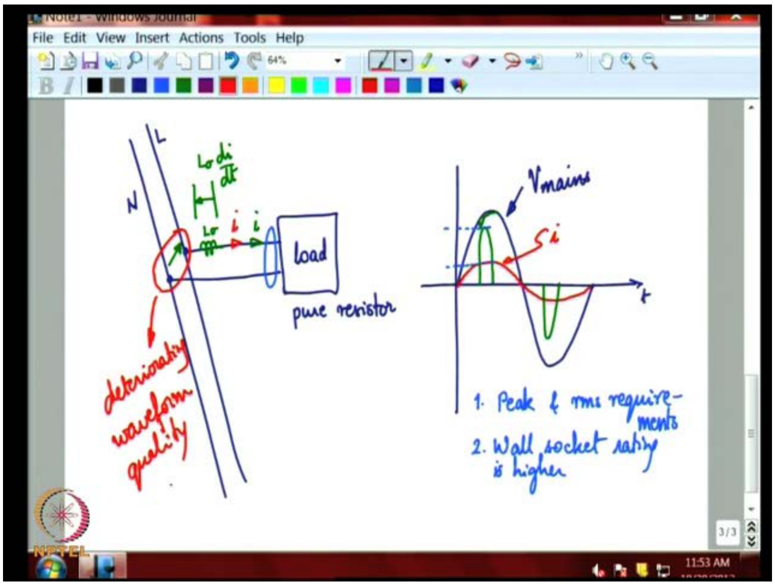

I if take the grid the mains, which is two lines light and neutral and too that there are many loads collected, let us say variable loads. Now, if this load were purely resistive, so purely resistive, then the nature the current here, would follow the voltage wave shape.

So, if the voltage vary sinusoid, then the current this is v mains 230 volts, the current would also have similar wave shape just like the voltage, it is the current i. Now this is a purely resistive load, now let us same, we have code the rectifier capacitor type of load, what is the type of current i that you would expect. So, the current that we expect is something like this, now this is the current i that would actually flow out from the mains into the load. Now, because of this there are many problems, that you can in the search.

First of all the peak and rms requirements, now you see that, if it had been for a given power the same power fixed, for the resistive and that for the capacitive filter load. The peak power requirement, for the resistive load is much lesser than the peak power requirement, for the capacitor input filter type of load the same power. Because on a averaging this, so this area and this area is same. So you will be delivering same similar power because the peak power is larger, the wall socket rating for a capacitor input type of circuit will be more for a given load than with a resistive.

Not only that wall socket reading is higher, which means the mains should be capable of giving a much higher power even though the load power is smaller. The another important issue is there will be the stack inductances impedances, so when you draw a large spiky current there will be a drop, which is some L sigma di by dt across these track inductances. So, larger the di by dt especially in this higher rise time zones, you can have a large voltage across this l sigma and it will start corrupting the mains. So, at the point of common coupling, you will see there will be a dip and then flattening out, so the voltage waveform at the point of common coupling, start deteriorating waveform quality of the voltage.

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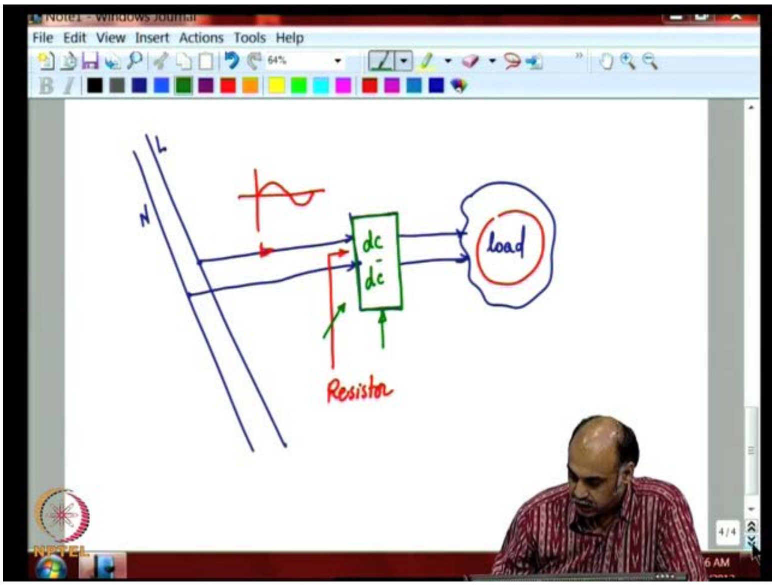

Now, because of all this points, we need to ensure that to the grid line in neutral. Whatever may be connected, whatever may be the type of the load this interfacing circuitry, which you are having in between should be such that as far as the grid is concerned, when the grid is look from this side, its looks like a resistor. Such that the current waveform here, is always sinusoidal in phase with the voltage waveform irrespective of the load. Now how do we do that? This interface box should adjust its input impedance, should adjust its input impedance based on some control sends from the load and the input signals.

So, this can be the DC DC converter, now among the DC DC converter if you take the boost converter, the boost converter has the inductor on the input side, which means the current is smooth on the input side. The boost converter has the inductor on the output side, which means the current is smooth on the output side not on the input side it is switching. So, boost converter has the tendency to smoothen out the input current. So, let us have a look at the boost converter and see, whether it can be used as a variable resistor or a variable impedance.

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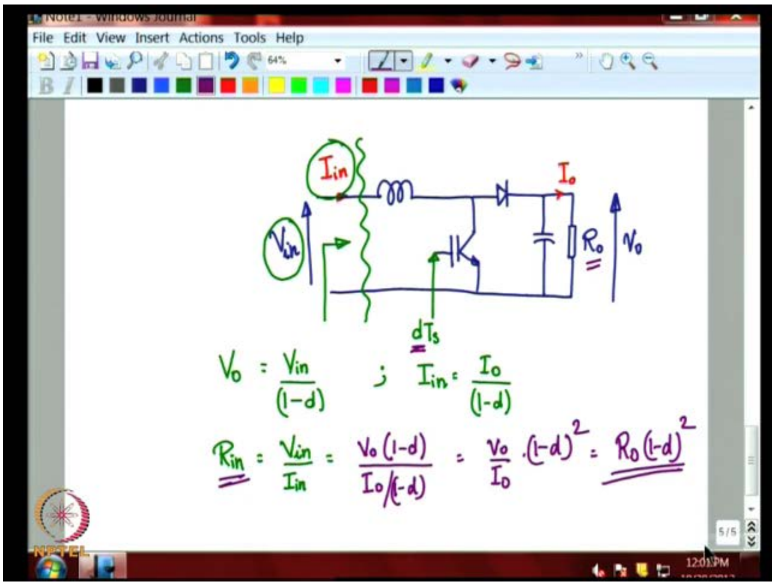

So, let us draw this boost converter, the boost converter has an inductor and has a switch a diode capacitance, R naught this is v naught it is a dc, now let us say this is v in. We shall also now consider two points, one is the input current i in and the output current i naught all are dc. Now, what is the relationship between the input and the output? With the input with the control input being the switch gate side, it is on and off for dts period of time. So, we know that for the boost converter V naught equals V in by 1 minus d, where d is the duty cycle. Now, there is another relationship between I naught and I in, let us say I in is equal to I naught by 1 minus d, this is by power conservation we know that v naught I naught is equal to V in I in. Now, what is the input impedance R in, as seen from the input side.

So, it is nothing but, V in divided by I in, so r in is nothing but v in divided by i in. So, let us use this our relationship V in. V in is nothing but V naught into 1 minus d divide by I in is nothing but I naught by 1 minus d, which is equal to v naught by I naught into 1 minus d square, or R naught into 1 minus d whole square. So, you see that R in is the function of d and the output load, so as the load varies if you modulate your duty cycle, you can control the input impedance. So, by adjusting the duty cycle, we should able to control the input impedance, such that whatever be the load condition the input, can always see the desired input impedance input resistance.

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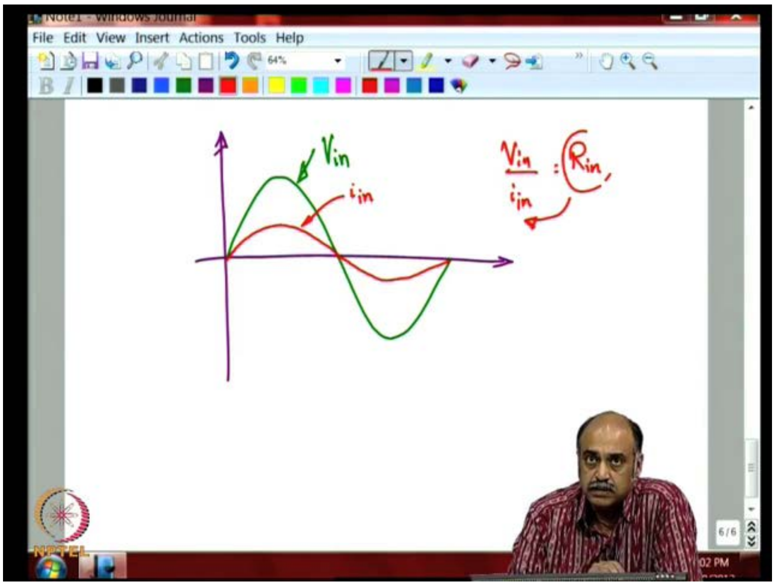

Or in other words you control the impedance, such that the input voltage wave shape is this is V in control the impedance, such that i in is of this wave shape this is i in. Such that v in by i in is equal to R in and this is controlled, such that you get this kind of the wave, wave shape. So, this is in fact the concept that we will be employing, so we modify our rectifier filter in the following manner.

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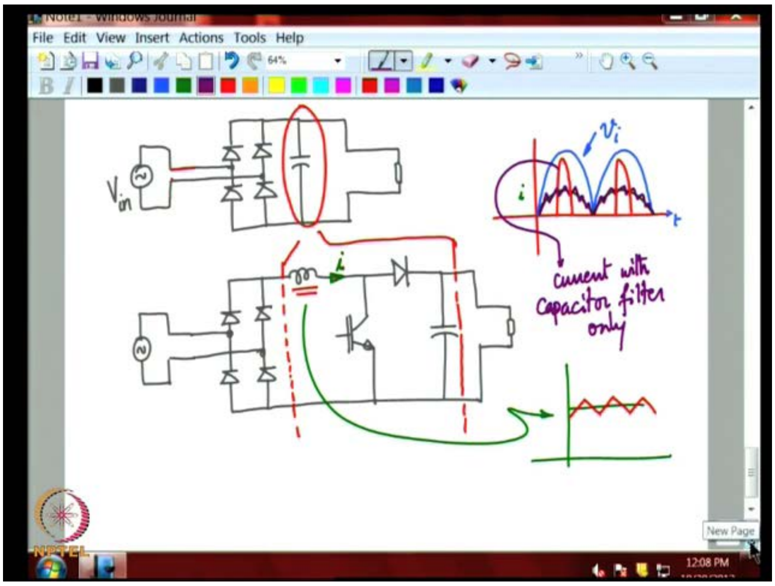

The rectifier filter was in this form, let say this is a load I just put it as a steve load, it could be any load for that matter. We have the sine wave shows coming from the grid, this V mains or V i. Now, this is modified in the following way, we still retain the rectifier portion like this, so up to this portion we are going along with the previous circuit and then from here, we start using a boost converter. So, this is a boost converter, so this portion is now your replacement for, so this is a rectifier for the boost converter and this inductor will do the current smoothing

Let us study this circuit, what is that current wave shape here? This will be a wave shape, which should follow let us say the input voltage pattern, this would be the virtual v after rectification v i after rectification this is versus t. The current should ideally be like this at this point current I, however because of this switching nature the inductor current, will not be just nice smooth dc, it will actually have an upswing downswing upswing downswing like this.

Therefore, we can expect that, we should have a kind of a waveform with switching ripples like this. Now, if we get this kind of wave shape, that itself is a fantastic improvement as compared to a capacitor filter kind of current that we used to have. So, this was the current with capacitor filter only immediately after the rectifier through this. So, the improvement would be significant just by using the boost converter and modulating the switch with pulse width modulator, in order to get us one near sinusoidal input current.

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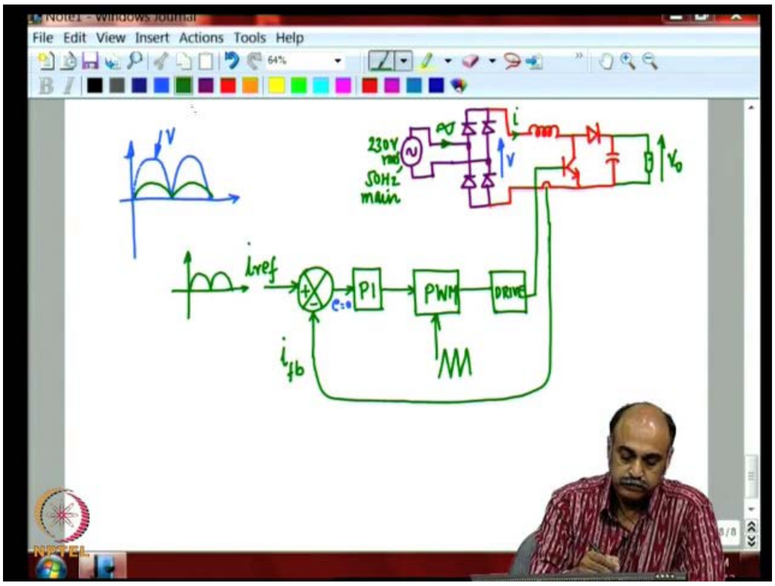

So, let us look at the complete circuit in the block diagram, so let us have our boost circuit. Here, we write that once more this is our rectifier and boost, this is the boost part of the circuit and then you have the load though I am indicating here with the resistor flow. This is v naught this is 230 volt rms 50 hertz coming from the mains and we want to control the input current i by controlling the gate pulses, that you apply where?

So, let us have a reference, let us have a current reference a comparator, the output of the comparator goes through a pi controller output of the controller, goes through pulse width modulator .You have a triangular carrier output of, that goes through the tri circuit, which drives the power switch. Now, what do we give here, we need to feed back and we shall feedback the inductor current ,you could sends the inductor current at this point. So, let we erase that point at now, so let us sense the inductor current and pass it here, this i feedback.

What is the nature of i reference? We would like i reference to be sinusoidal, such that i feedback would also be sinusoidal, whatever may be the load. Sinusoidal meaning, this should be in keeping the wave shape of the voltage wave shape. So, let us see how do we get the reference? So whatever be the reference i feedback would follow the reference ,what that the error here is 0. Because of the pi controller takes care of that, it will adjust the pulse width pwm here accordingly, such that the error here is 0. Then the feedback i feedback portion will be same as the reference, which means the current here would be same as the reference.

So, we should probably give a proper reference, so let us see what, what is that, if we would want reference to be. At this rectifier output, what is the voltage? The voltage is virtually a rectified full wave rectified waveform something like this, this is v let us say that we expect here. What is i that we expect, the i that we expect here, is to have similar wave shape unity power fact. So, I should give a reference, which is like this, then i feedback will have a voltage wave shape like that and the waveform here, would be a pure sinusoidal waveform before rectification. There is also one another issue we, we need to understand here, what happens, when the power increases or power changes or else say the load changes power changes.

Now, let us say the load decreases power decreases, if the power decreases the current here, would decrease or otherwise let us say the input mains is unregulated, if this voltage increases the down stream converters will have closed open it will try draw only the same power, so we will a constant power load most of the cases. So, with the same power if the input voltage increases, so current should decrease.

So, in some way the amplitude though the wave shape is supposed to be exactly like the voltage wave shape, the amplitude should be decided by the power drawn, such that this current amplitude and the voltage amplitude together, will be the power that is required by the load. So, how to bring in the dependency on the power, let us look at the reference current requirement with more and detail.

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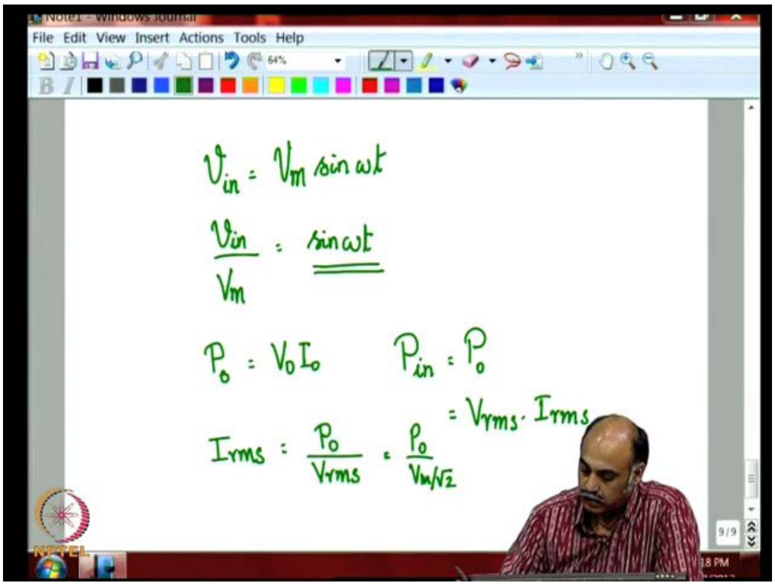

So, we know that v v in is equal to v m sine omega t of this form the voltage of the mains or omega t. Now, v in by v m is sine omega t, now we get the wave shape by normalizing the input wave form. So, the voltage normalized with the max value v m value, would give you the wave shape. Now, we need the amplitude of I m for I m. Now, what is power p naught, which is equal to V naught and I naught. If you consider 100 percent efficiency, p in will be p naught and p in is nothing but V rms into I rms if both v and i are sinusoidal. Therefore, I rms is nothing but p naught by V rms, assuming the efficiency as 100 percent.

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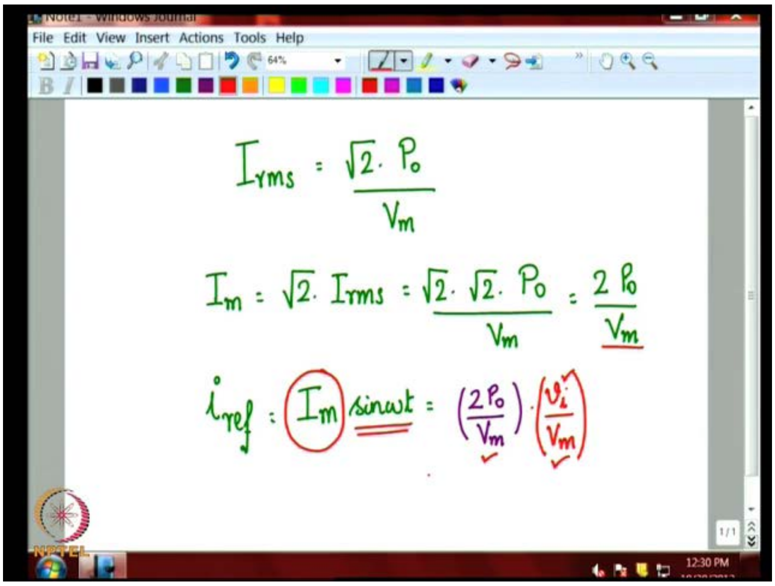

Which is nothing but p naught by root 2 p naught V m by root 2 is root 2 p naught by V m. now, what is I m? I m is equal to root 2 I rms, which is equal to root 2 into root 2 into p naught by V m, or 2 p naught by V m. What should be our i reference? In an ideal case the ac waveform, should be I m sine omega t. Now, let us replace this with this, so you will have 2 p naught by V m representing the amplitude and for sine omega t, we will replace it with V i by V m from copying from vi is equal to V m sine omega t. So, this would give a reference, this is would measurable this is also measurable and we know, what the peak value is this is the peak value p naught can be measured from V naught and I naught, which is measurable.

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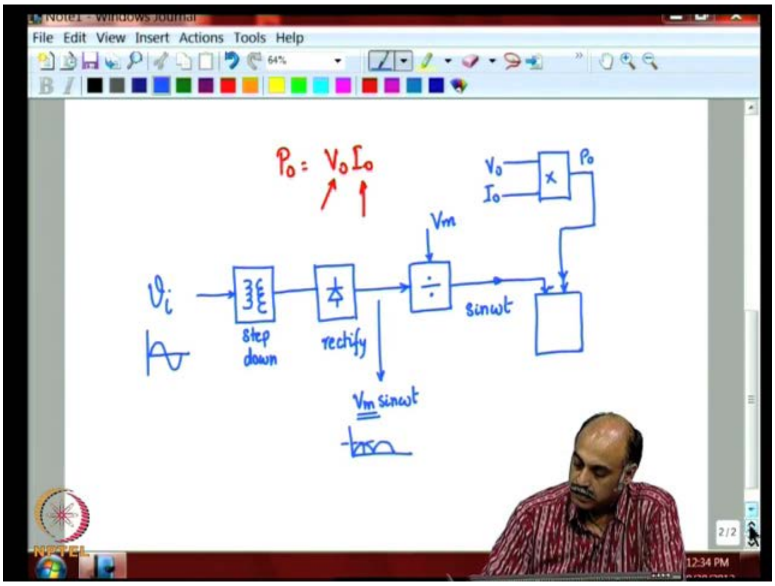

That is you can measure P naught is equal to V naught I naught, you are anyway measuring V naught, you can put a current sensor measure I naught and you obtain P naught. Therefore, if we if we take the original input wave shape v i v i, which is sinusoidal wave shape, pass it through transformer step downed rectify it rectify what do we get here, here we would get something like this. Now, this… divided by V m, which would correspond to the voltage amplitude here, this V m sine omega t of course rectified. So, this amplitude is V m, now I am divide by that, you would get sine omega t same wave shape as this but, normalized. Now, you have sine omega t here, you measure V naught measure I naught multiply, you will get p naught and this can be brought to one more box.

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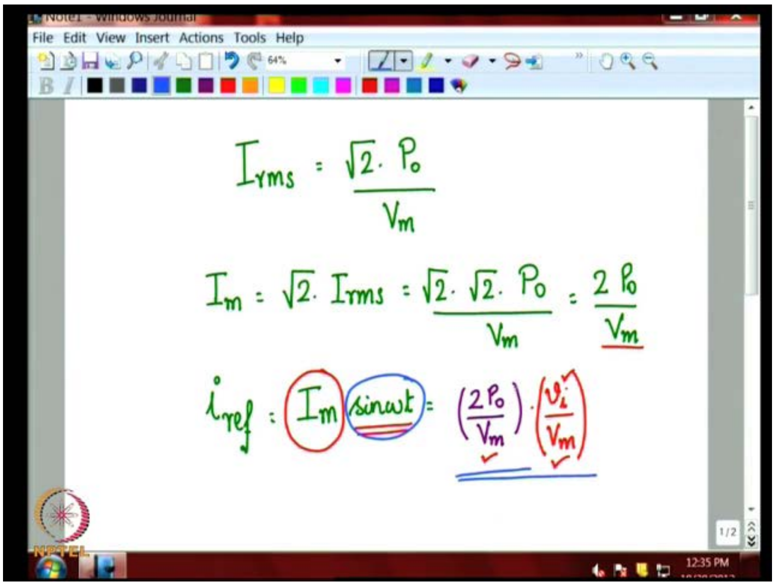

Apply this function, this is nothing but sine omega t, which we have got and this is something we need to.

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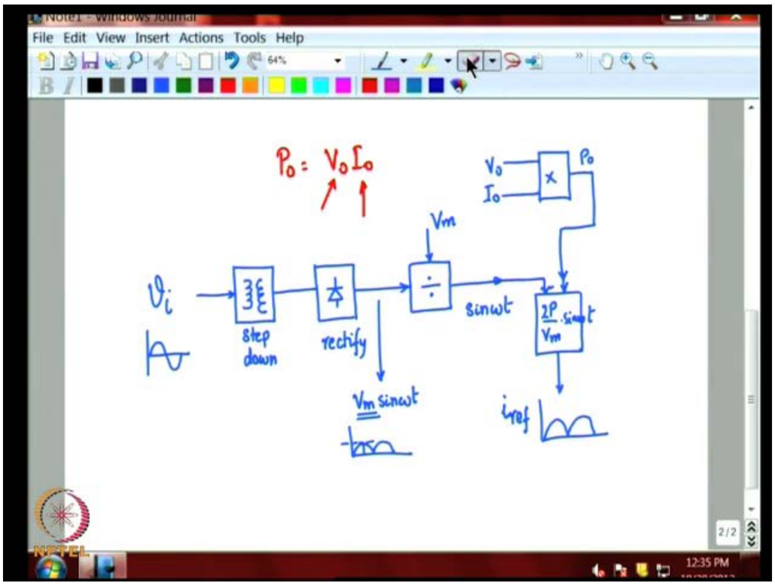

So, 2 P naught by V m into sine omega t, which would be i ref.

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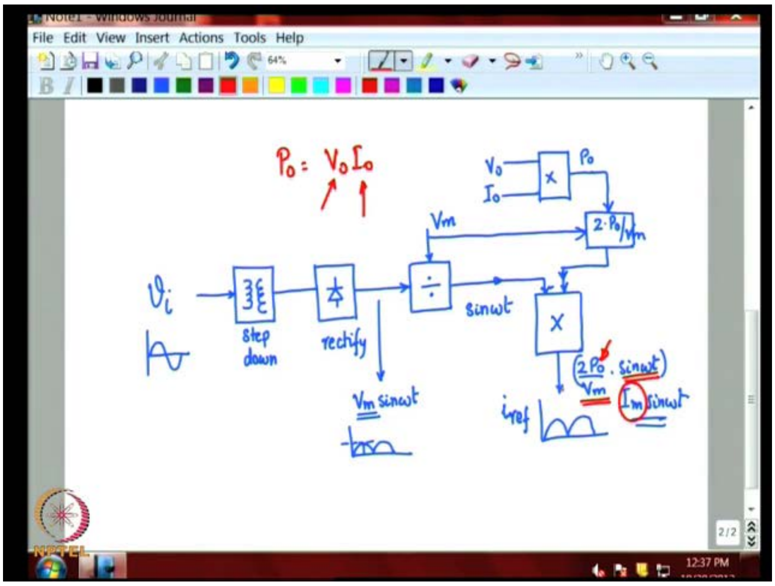

One intermediate block which you could fit in here, p naught V in V m so 2 into p naught by V m can be calculated there, bring that and then put it here this is nothing but a multiplication block. So, this will give you 2 P naught by V m into sine omega t or I m sine omega t. Now, if p naught increases I m would increase, if p naught I m would decrease or if V m increases I m would decrease and the reference will accordingly change based on p naught and the wave shape of the input voltage. So, observe here, 2 important things the amplitude of I m changes with P naught controlled by P naught. The wave shape is controlled by the input voltage.

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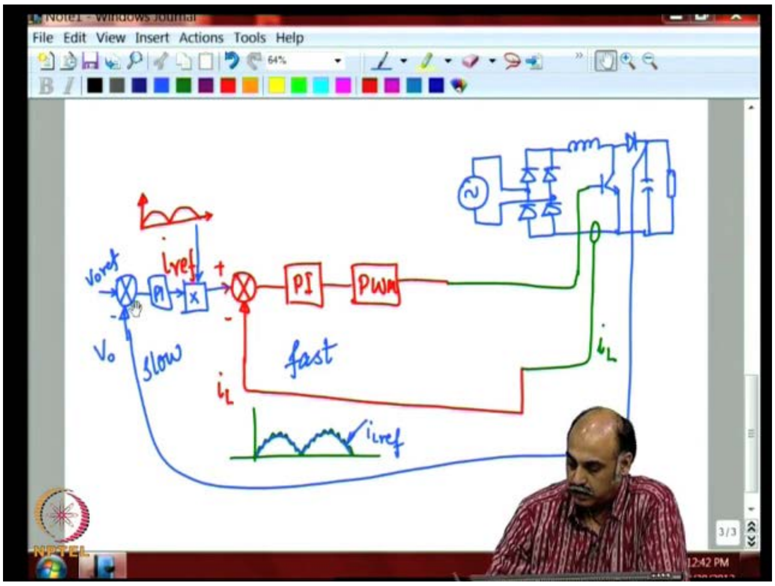

Now, this becomes i ref, which is actually the reference, which you would give to the controller PI PWM boost feedback of i this is i ref, which is something like that. So, in the end, in the end, we will have circuit, which is something like this… this is controlled by this and current i is measured i L is measured and taken as feedback. The current here, the inductor current will appear in this fashion, with the switching ripple in keeping with the wave shape of i L reference. So, this way we will achieve a unity power factor action and improve the power quality of the grid.

So, here I have shown only the current loop feedback, there can be one more slow. This is the current fast acting current loop, you could have one more outer feedback loop, a very slow acting voltage loop v naught ref V naught ref v naught feedback. Which will what you lead this current and give it here, so the amplitude of this current can also get modulated affected by this V naught feedback, which you will take from here. So, this outer current loop is very slow, this should be slow this, should be fast only. Then you will get effective unity power factor action and most of the time, you can do away with the outer voltage control loop, because most of the time the output is given to another load or a converter, which will take from this 325 to 400 volts dc.

Then develop the plus minus 12 volts 5 volts for various other application ,they have very fast acting, good regulation regulated converters and. Therefore, it can observe the unregulated voltage, which occurs here. Therefore, most of the time, you may not find it necessary to use the outer slow acting voltage control loop. But, any way to bring a arrow down the band of voltage variation, one may use the slow acting outer voltage control loop. So, this is a unity power factor operation for you.

Now, that we have covered the basic converter topologies, the isolated converter topologies, non isolated converter topologies. Also the various aspects of control starting from voltage control to current control and how we build the controller? The pi controller various other control structures. How we design it using the root locus method, and to and also by the trial and error approach? Now, we shall try to look at some examples of controllers DC DC converters and say, how we go about designing it.

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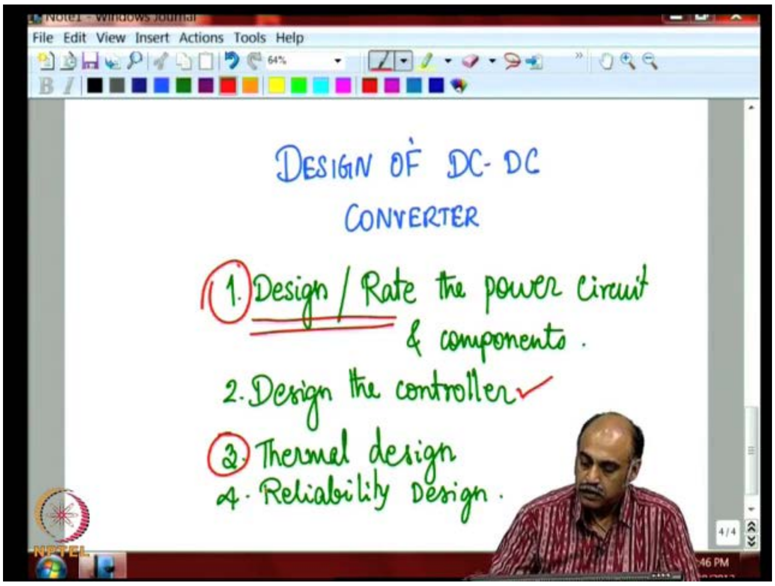

So, when we design a controller, design of DC DC converter, there are many aspects to it. One is design rate the power circuit and components, second aspect design the controller and thermal design, designing appropriate heat sinks for the power semiconductor switches and you also have, reliability design designing for a given reliability. So, all this aspects should be put together to realize a proper performance measure. Then after that there is also another measure, which is the cost. How do you realize the given performance for a particular specific cost?

So, for now in this particular course, we shall try to a look at aspects of this designing the controller we have already seen, we shall probably look at briefly some aspects of this. Reliability design and cost design is out of the scope of this particular course and therefore, we shall not look at it but, in back of your mind keep that, this two very very important aspects, that are essential for full complete practical realization of the product.

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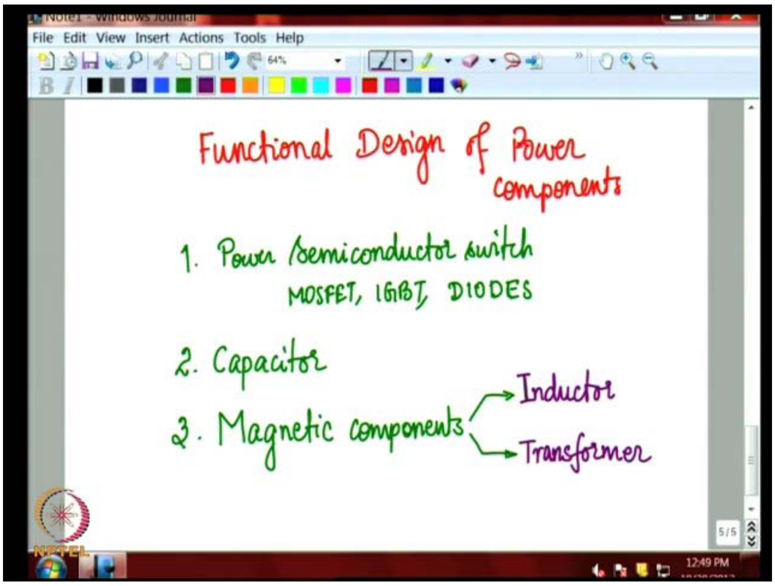

Now, when you come to functional design, functional design of the power components, there are few aspects related to that. One is the power semiconductor switch, which is the MOSFET or the IGBT, diodes, these are all power semiconductor switches. You need to appropriately choose them, for the particular application its current ratings, its voltage ratings, thermal ratings all these have to be appropriately considered. Then a proper device has to be chosen, for that the particular specification, how do we about doing that? We shall do we shall look into that aspect in the next few classes.

This second part is the capacitor, we need to size rate the capacitor true, what would be the size of the capacitance, what should be the sr of the capacitance, should it be an electrolyte capacitance, tantalum capacitor or any other special types. What are the issues involved it is also another important issue that you need to consider, and look at the data sheets of these components. Third very important is the inductor or I will generically call it magnetic components in the non-isolated case, you have only the inductor to handle deal with and in the isolated case, you have both the inductor and the transformer galvanic isolation. So, you have two components; one is called the inductor and the other is the transformer. Now, both these components need to be designed and especially in the case of the inductor of the transformer, there are two aspects to it.

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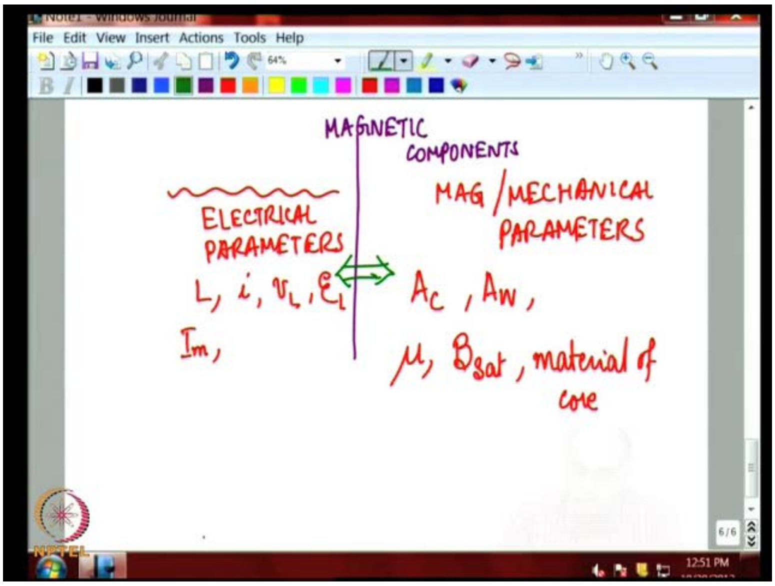

So, the magnetic components on the one side, you have electrical parameters like, the value of the inductor, the currents through the inductor, the voltage across the inductor or the magnetizing current through the transformer or the energy that the inductor has to store. These aspects, and on the magnetic and mechanical parameters, you have the cross section of the core, the window area of the core, you have the permeability, the saturation flux density, the material of the core, all this play an important role. We need to interface these two to realize a proper magnetic component, so how we go about doing all this? We shall discuss in the next class and next two classes to come.

Thank you.