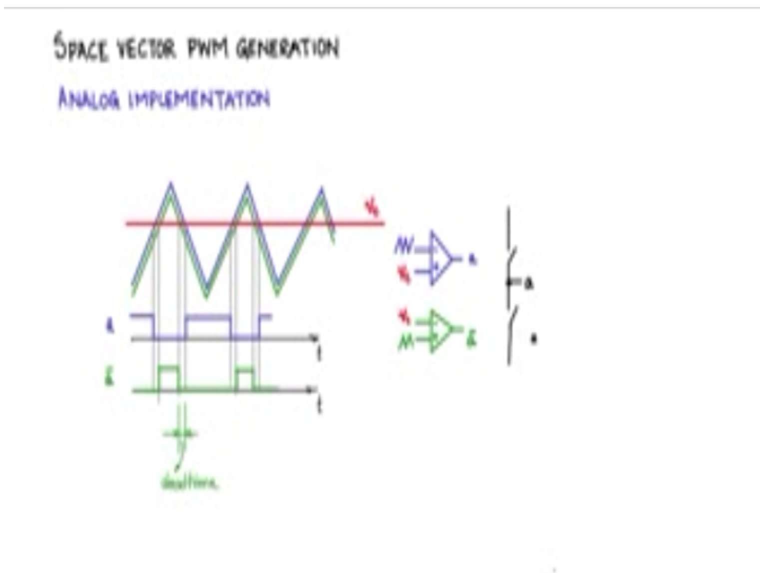
Indian Institute of Science

Design of Photovoltaic Systems

Prof. L. Umanand
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

NPTEL Online Certification Course

(Refer Slide Time: 00:17)



Let us now discuss the space vector PWM generation by analog implementation this would mean implied that we will be using atoms just like in the case of the discrete the principles remains the same instead of compare we just will be use often comparators and instead of time will be using it triangle way generated.

Consider at triangular carrier like this and then from this triangular carrier I will generate another triangular carrier which is slightly of set in this fashion reason will become clear shortly and let us say that I am now comparing this with some modulating signals Vc let me now draw the intersection points drop down the intersection points of the modulating signal with respect to each of the carrier.

The blue the top carrier and the green the bottom carrier the intersection points are like this and dropping them down and let me have two axes time axes both are time axes and let say one is representing for the top space and other is representing for the bottom space of one or more inverter so let us say this is the A of the inverter the top switch the bottom switch.

So let us say the top switch I will use something like this our comparative plus minus like this and let say if I am calling this as Vc I will give Vc to the positive and to the negative pin I will give the blue triangular carrier in this fashion now what is the output which is supposed to go to the top switch call that as A.

Now whenever Vc is greater than the triangular carrier we high so Vc is greater than triangular blue carrier it is high you see the intersection point blue is here it will go down and ten again come up at this point and then go down here come up in this fashion now for the bottom switch I will use another comparator like this and now I will give for the –Vc and for the + I will give that green triangular carrier.

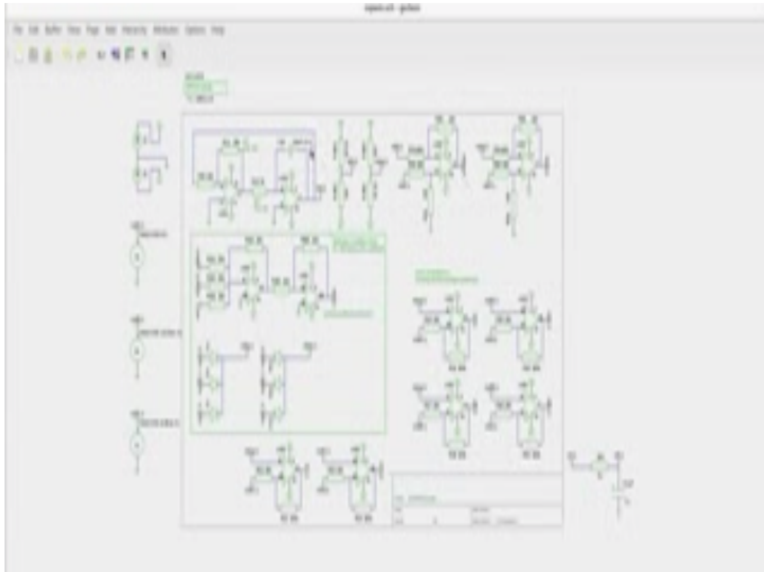
The one which is of set so in that was this will be A bar so now A bar so whenever the triangle is higher than Vc to be positive so you see here by intersection points it will be positive at this in this fashion like this so now you see the beautiful aspect of this is that during the transition this is not direct 180o inversion as I was saying before you deviated time when this transiting down from on to off and this is transiting from off to on.

There is a period called a dead time likewise this is transiting from high to low and this is from low to high there is the period where there is the dread time of both are off this is called dead time so that the top and bottom switches are given enough time for changing the state because they are having fine height risen for times.

They are practical switches so this is called the this time interval is called the dead time you include the dead time in analog case by this manner by introducing this small off set between two carrier of the same frequency where as the case in this discrete case you include the dead time by having a small lope it count counter and introduces the dead time by adjusting the count value.

This would inter principle be the way it is implemented in analog there is one more small item that you need to include which is injecting thermo monies why and how I will tell that so let us say this is done for each of the phase each of the arms that is you have their arms for the three phase let me just show this implementation first in Ngspic schematic.

(Refer Slide Time: 05:14)



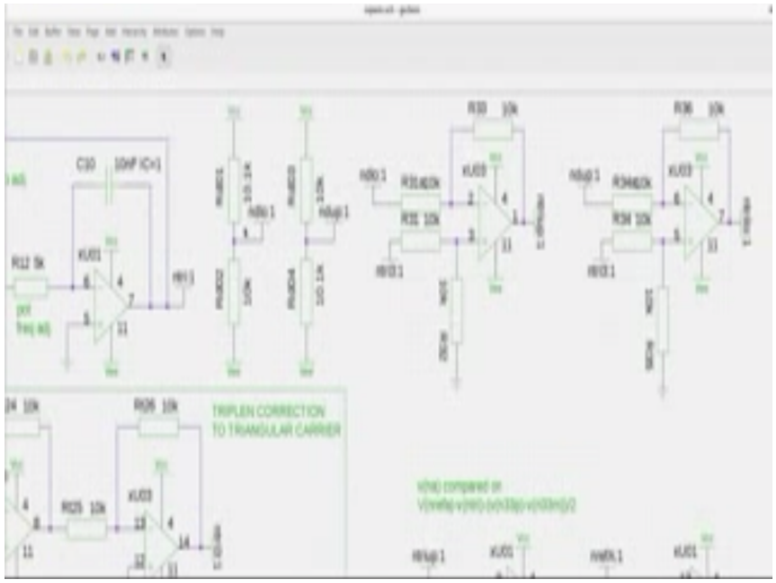
And then I will come back to the modification that we need to do on this so you see here this schematic SVPW.SCH and within be the page boundary I have the circuit and outside the page boundaries I have some portions of the circuit like this sources the dc power supplies and them faltering here outside these are actually not part of the PW circuit.

Because if I have to make a PCB out of it I need to use only what is inside the page and then put connectors to wherever these items attached so I have put all this external components for simulation purposes and what is there inside can ebb directly send for making it easily okay now this opams the symbols of them and the models of this opams or in 01.SVP the symbols.

I have already provided for you in your mind earlier resources now I will explain this part for now this internal square block fro get it let us just see the triangle and comparison now this portion is the triangle generator so it is nothing but if I expanded that zoom in so I have opams here this is nothing but integrated and output like integrated is compared.

It is comparator so let us say at I give an point in time when this goes high this starts integrating down because of the capacitor this will discharge and this voltage is going down and as it is going down one set crosses the whatever the hysteresis is lower drip point limit this will go low and again this will start rising because there is the change in the state here.

(Refer Slide Time: 07:49)

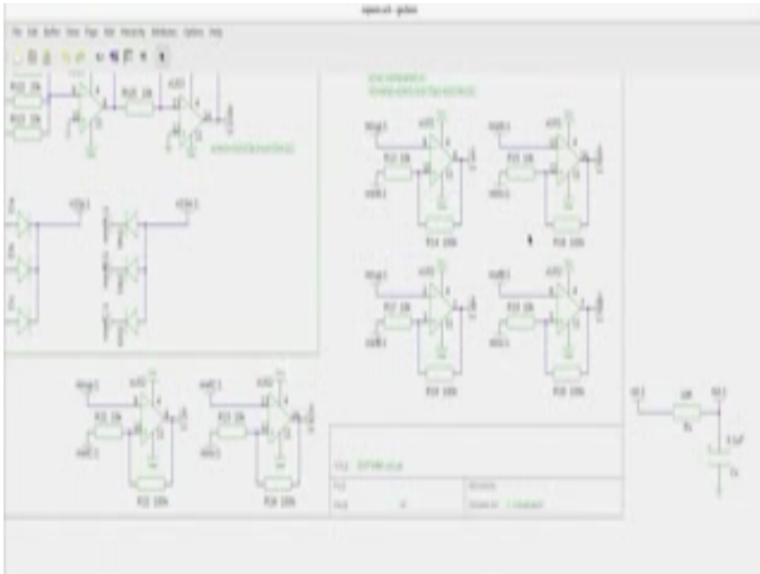


Now the current flows charges of the capacitance nod this will rise and then again it goes above the upper drip point this will change state so what so you will get here at this point at triangle way form you can simulate in that and then check it and next what I do is I am introducing this off set since I am using this triangle.

And having now let us say there is the resistor divided network here another resistor divided networks here I am making the attenuator point not enclave one is 10.1 K no one case the upper resistor is 10.1 K in this case the lower resistor is 10.1 K so this will be slightly higher part value and this will eb slightly lower value compare to 0 because this is the positive and the negative.

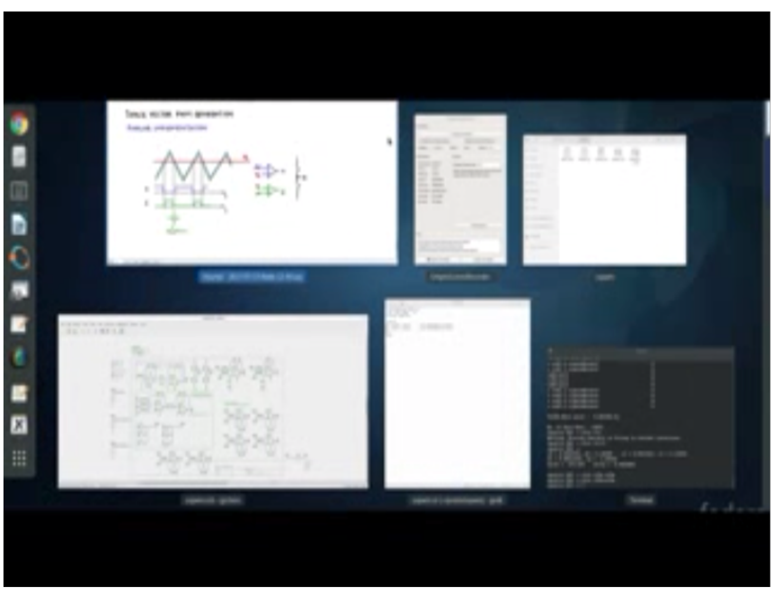
And the higher and the lower values I am going to add to this triangle so one of the adder I will take this triangle and add it to this off set I will get one triangle itself blue than to the another one I will add the other off set and I will get the lower triangle so these two triangles will be having as slight off set between them.

(Refer Slide Time: 09:11)



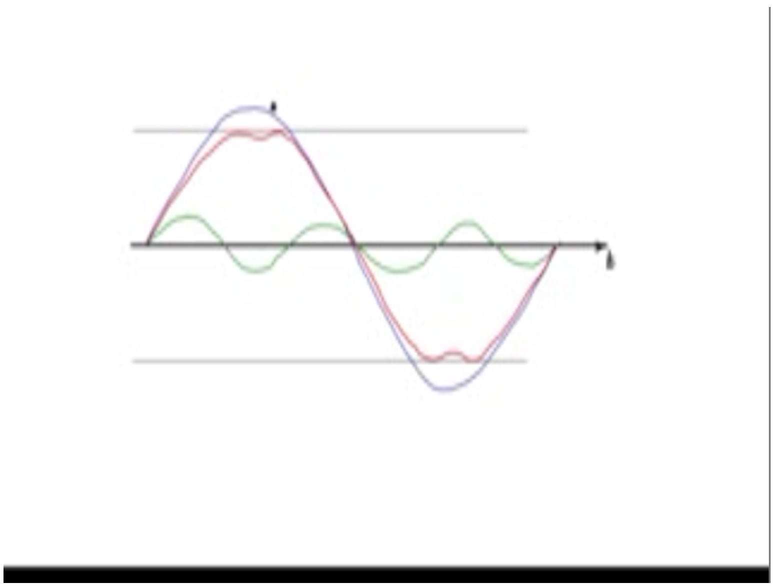
And that is what we want to use for comparison so them after that I will I sue set of comparator we need two comparators for each arm so arm 1 arm 2 arm 3 so like that so for the A phase the B phase and the C phase so I am top side bottom switch so for one you will compare you will use triangle off for the other you will use triangle low triangle up triangle low triangle up triangle low just like I have discussed.

(Refer Slide Time: 09:52)



So withy hysteresis you will get the PW at the output switch you will give for the top bottom the top bottom top bottom like that so each other arms so this is the basic working now in an normal in an normal PWM this is synodial PWM this is fine but in a space vector PWM the third harmonic is injected.

(Refer Slide Time: 10:09)



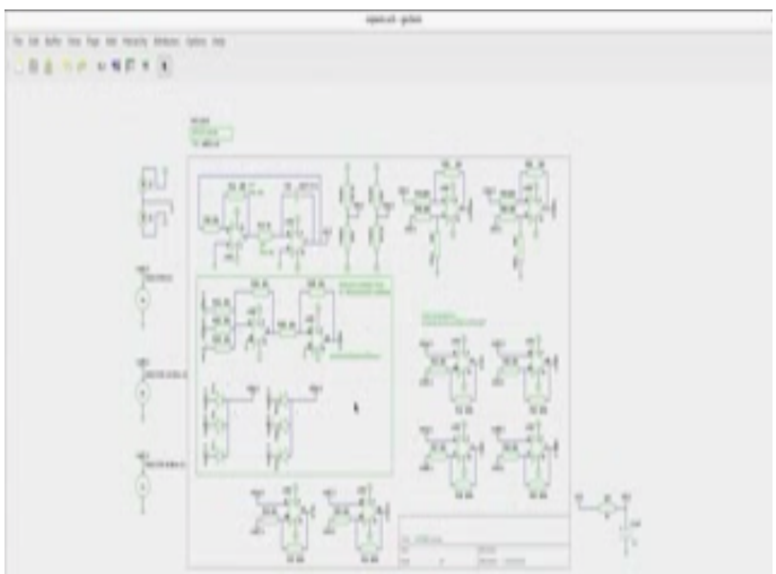
Now why is the third harmonic injected consider this at time line and signal I have this time now I have this extreme limits this is 100% modulation this two limits or indicating 100 as sign just touching this line will give you 100% modulation now let us say I have a sign like this with the shooting over the more than 100% and I modulate this.

You will see that once is 100% modulation reached it is no longer it goes to over modulation it is no longer linear and proper way from PW will not be obtained now what we can do is now let us say I have this third harmonic okay this is the third harmonic thread line and I will use this I will subtract this from this.

So if tripling is injected in three phase system it is not going to affect it because it does not providing the rotating phase R and therefore when I subtract it you see that the top forum gets doom subtracted it because of this so you will see that the wave shape takes pressure something like that so you will see that this is just within the 100% modulation.

Now this tripling compensated wave shape the red one is if I use as modulating signal then it contains within it the fundamental which is more than 100% and therefore I am able to get more than this 100% modulation possibility if I am injector plan so in space vector modulation we use this technique of trying to get more fundamental out of it. And normal synosdial will give you at just about 100% and where as space vector PWM because of this can give up to 114% so that is extra mileage that you can get so that is why third ref harmonic is added.

(Refer Slide Time: 12:35)



So coming back to our schematic this portion of the circuit is how to add the third harmonic component so here the carrier is this triangular generator here and the modulating signals Va Vb Vc torque is coming from here now one can add that tripling third harmonic to the input reference wave and then use it for modulating or you can add the correction to the carrier itself.

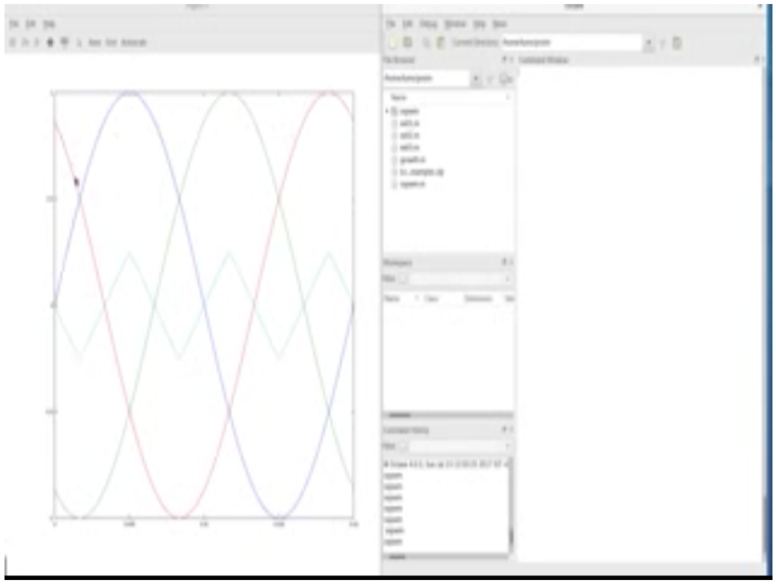
And then not add any corrections to the input reference wave shapes it is easier to add corrections at single point that is instead of adding correction to every all three phases you can add it you can add the correction to just the carrier and then get the same effect.

(Refer Slide Time: 13:32)

Let us understand this by going to octave I have small script written SPPWM.M so here what I am trying to do is what is the effect of third harmonic tripling injection into the fundamental and what are the advantage you have again in SPPWM because of the third harmonic see in that discrete case because of the offset we had included the t knot is the 0 space vector case while corresponding to that.

And it is not equal on both sides t knot by 2 they are varying by the as the envelope is changing so third automatically the third harmonic gets into picture and because of that you get that extra mileage of 14% more fundamental as compared to the regular synosdial PWM so here in the script I have first point is generator the three vectors.

(Refer Slide Time: 15:17)



So we have the four three sign waves so let me execute this SPPWM so I first plot these three sign waves that is what I am plotting here first now consider this wave shape the max of Va, Vb, Vc would be this envelope this torque envelope here and the mid of the Va, Vb, Vc would be the bottom envelope so you take the top envelope separately take the bottom envelope.

And then take the average of those torque the bottom envelope is having negative values the top envelope is having positive values the positive values+ the negative values by 2 and tahtw oudl be this wave shape now this wave shape is actually the third harmonic you see that there are three peaks we can have a cycle so that is the tripling so I have the tripling here now what I have do with this tripling.

Let us say I have the fundamental this fundamental minus this tripling see the third harmonic will not contribute to the rotating space vector because you have this -2π/3 -4π/3 three times if you do it will become 2π and therefore there is no contribution there is no phase difference and no contribution to the rotating space vector.

So you can safely add tripling harmonic so to this fundamental I subtract this tripling what happens so if I subtract you see that to each of the original wave form fundamental I subtract this tripling you see it becomes something like this the top is flattened out and then you see that let us say the level the modulation level has come down.

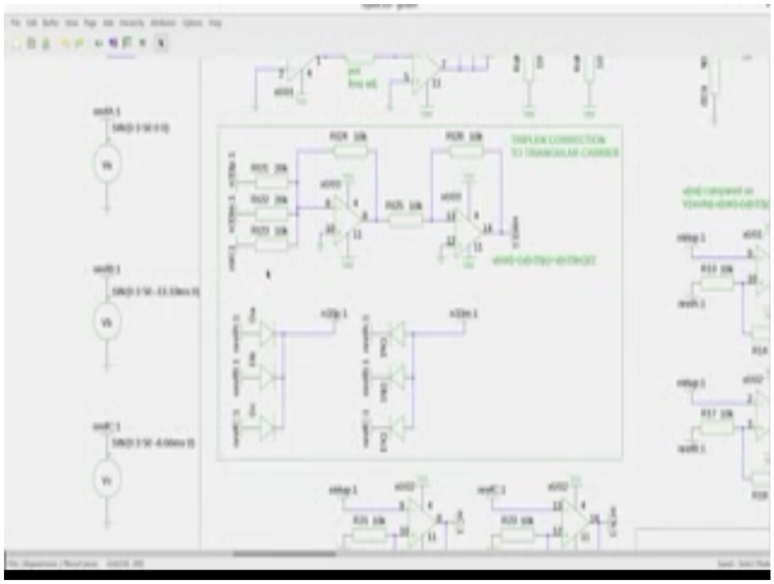
So for fundamental of one unit the modulation required with the tripling injecting modulating wave is much lower let say .86 now if this modulating ratio that reached 100% then the fundamental that you would have gain loss much more 14% more you have got 1145 fundamentals so that is the extra mileage that you would by injecting tripling into the modulating signal.

And then doing the PWM so that is why SPPWM or the space vector PWM as that extra advantage now one can inject this tripling in this fashion as I have done so I have calculated all the positive envelope by taking the max of Va Vb Vc at any incident and the bottom envelope t negative I would calculated by taking the minimum of Va Vb Vc vector.

Now the tripling I take the average of these two be positive + negative/2 and that is the tripling wave shape the saw here this sir the tripling wave shape this I subtract from the original synosdial modulating wave shape what I do the tripling injected Va would be Va3 is Va- tripling Vb3 is Vb-triping Vc3 is VC- tripling like this.

So now Va3 Vb3 Vc3 are continuing tripling and an if you plot that tripling wave shapes you get something like this so if I plot it alone you will see that let me remove this plot so you will see the wave shape something like that with the top flat end out which gives the extra mileage for the modulation now one can add one can minus subtract the tripling from the original synosdial modulating signal or one can add the tripling to the triangular carrier.

(Refer Slide Time: 20:25)

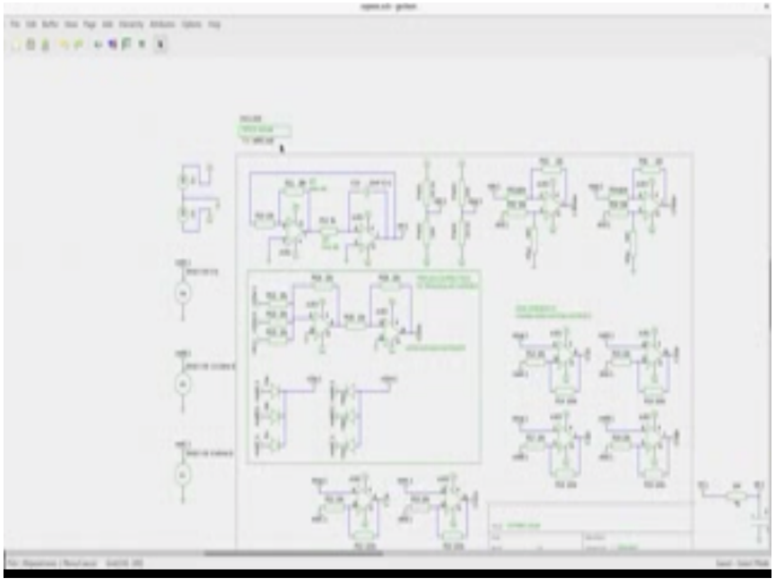


Both are fine so in the analog implementation case we have added the tripling to the triangular carrier if you come back to this schematic and if I zoom into the tripling correction part you will see that this portion is actually an adder so what is it doing now there is the diode and the inputs are the references the three input phase forms.

And this will take of the top envelope and this circuit will take out the bottom envelope so this minus this so this is positive this is negative so I can add here as of the triangle I will then scale it invert it so this point would be the character tripling in fact that is what I have actually used for doing the off so that would becomes the triangle for actually shifting the off set high.

Another triangle you obtain you obtain the triangle low by shifting the offset but the input I have using is the tripling character triangle so this triangle is used for getting the tripling character triangle and the tripling character triangle is used to create two triangles one up and one down and that is used for comparing with the opams with the modulating signals and then you get the PWM.

(Refer Slide Time: 22:14)



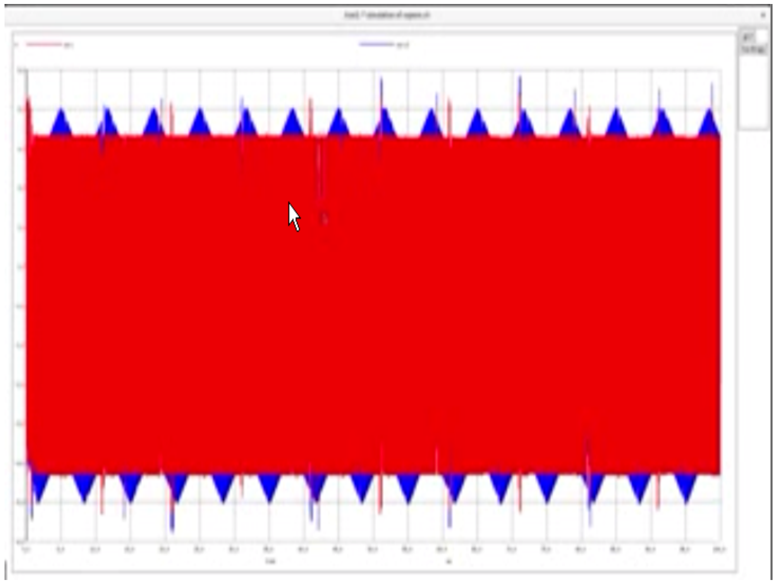
Now we can say try simulating this and see the way forms at various points observe that as before I have various models top and models also within that.

(Refer Slide Time: 22:23)

Now let us go to the terminal and I will use to obtain SPPWM.NET 5 from the schematic 5 so I now have the net list available with me SPPWM.CIR file important I am doing the fraction analysis it is including this SPPWM.NET 5 which got just generated and then I am as usual having some control statements and setting the background color to white and foreground color to black and then initiating the random action once I go into the environment.

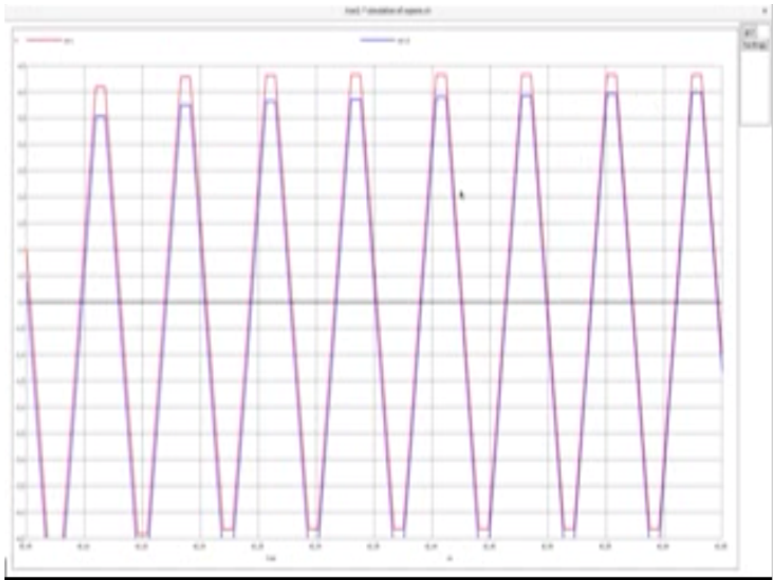
So this I will do I will close this and then go back to the terminals in the SPPWM.CIR so it will go in and execute the SPPWM circuit the whole entire circuit will be analysis plot what do you want to see now let us see whether this triangle is generated there is an n there is an no diagram ntri3 this six tripling compensated and this is the original triangle.

(Refer Slide Time: 24:04)



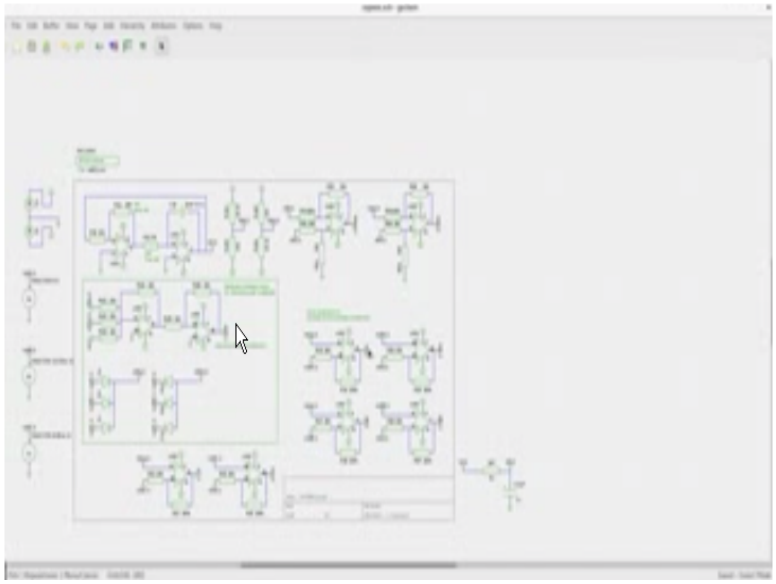
So let us go in the plot ntri and ntri3 tripling with the harmonics so if I blow it out you should see let me take the very small portion because this is the carrier.

(Refer Slide Time: 24:15)



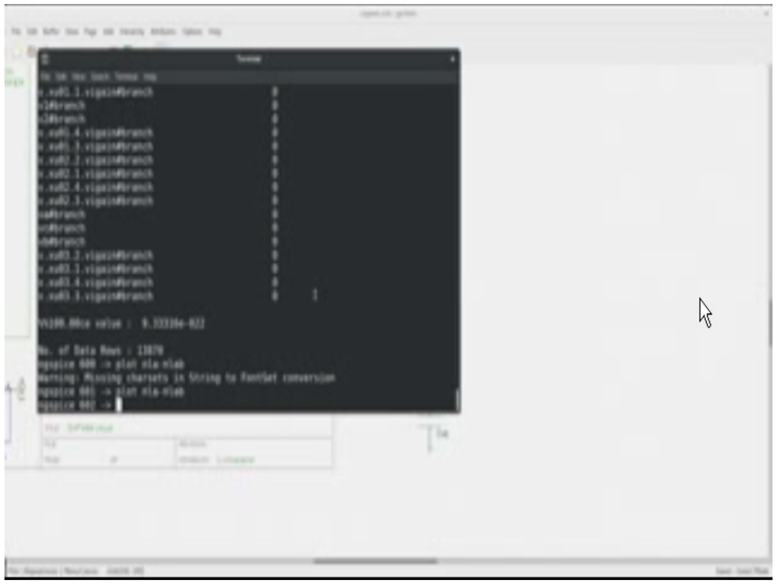
So you see that one is the constant one generate one is constant that is our original triangle and the blue one is gradually increasing and that is the tripling compensated one let me quit that.

(Refer Slide Time: 24:47)



Let us now see this schematic the dead time effect so we can go to the ngspice environment and plot that.

(Refer Slide Time: 25:08)



And look at very small portion and expand that so you can see already that there is of course these are display times if I increase the number of display points you will get much sharper wave forms effectively there is a portion of the time no overlap and that is due to the shifting of the triangles giving it small offset the two triangles one up and one down.

As I included to filters here one taking from this output and A and pass it through simple filters just to have a look of what is the kind of wave form that is there what is the modulating wave form we have introduces the tripling does it also have that tripling harmonic in the wave forms then I have executed it then I would like to show you the plot of observe this I will subtract at the channel A-channel AB.

So you see that it is continuing tripling portion the flat topic effect so the fundamental would definitely be much higher and because of the introduction of the tripling there is flat and because of the diodes that we have introduced there are some non linear effects which has come in obtained but these things will be the non linear effects due to non idealities of the components.

So in this way is PWM can be accomplished even within analog domain using opams I will shared this schematic with you, you can work on it and then try to get more insight with SPPWM.