Circuits For Analog System Design
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Module No. # 03
Lecture No. # 11
PID-Temperature Controller Design

Last week we have seen how to design a proportional temperature controller. This week we will see how to design a PI temperature controller.

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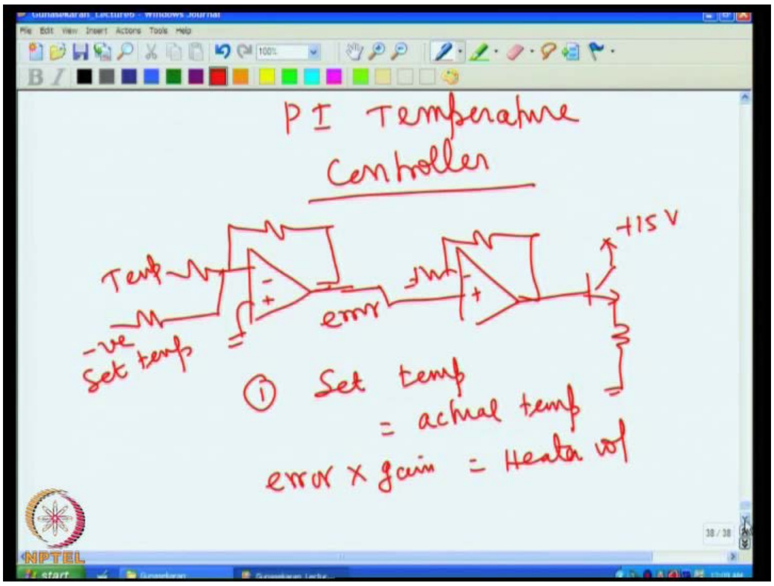

PI temperature controller - this actually gives much better performance than proportional controller so, this is extensively used. And we should understand why this integral action, PI - means proportional integral temperature controller. We also will see later, what is proportional integral differential temperature controller?

In proportional temperature controller, what we had done was - we had the actual temperature and then, we had the set temperature which is minus voltage, so that is given reverse of the set temperature. So, we got the difference between set temperature and the actual temperature this difference is called error voltage. Error voltage is amplified, and then given to the heater. Error voltage was amplified by gain time and then, that was driving the heater. This is what we had done for the proportional controller. The problem here was - the set temperature is not equal to actual temperature. So, if you set at 70 degree; you will not get 70 degree stabilized oven but, you will get little less than 70 degree. The difference actually depends upon how much gain that you had given.

So essentially, the error voltage error, into the gain is the heater voltage. Since, always we need a heater voltage and the gain is not infinity so always that is an error. But, if you increase the gain then error will come down. But then, you might have seen that, if you increase the gain; then the system trying to oscillate and this creates the problem.

So first, we see how to reduce these errors? Because, if the error is not there then there is no problem; we can reduce the gain and oscillation also will not be there. So, how to reduce this error voltage? That is, where the proportional plus integral controller comes into picture. This is a really great invention; it was invented by the practicing engineers, practically implementing this in many control systems.

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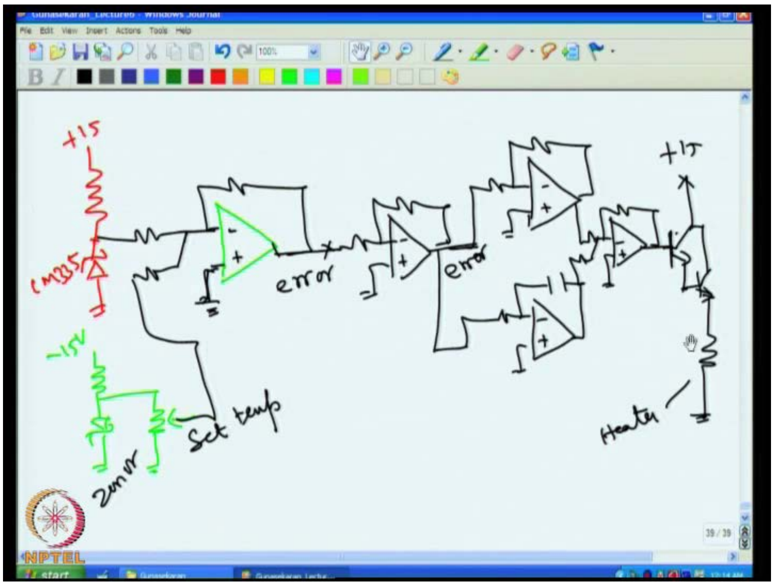

So the PI controller looks like this. So, you have say temperature sensor this is similar to what we had here. For example, I can give a LM335 as a temperature sensor, then I can also have reference voltage, so what we do is we give a minus, so that is easy to get the error difference. So, what we do is we set the temperature here and find the difference between these two; it is similar to what we had done with proportional temperature controller. What we do is we find the difference between these two, so I will find the difference between these two, so you will get error voltage that is the difference between the set temperature and the actual temperature, so this is a zener voltage zener so we fix the set temperature is here.

When temperature goes up, in this case this voltage will be increasing by 10 milli volt per degree C; and then since this is plus, this will be going in the minus side. So when temperature increases - you will be seeing that the minus voltage is increasing. If you want actually plus we can also change it; or we can invert it; or since it is an error voltage we have to amplify; and then add it. So what we can do is, if you want it we can invert it so that it becomes plus. Essentially, when temperature goes up, more plus voltage is coming here, and that makes this will go minus, and this will go plus. So you will get when temperature goes up essentially this voltage will be increasing.

What you do is this: we give it to a proportional stage, and then we give it to the so called integral stage. What we do is, we will just connect the integrator; now what we do is we sum these two voltages - I sum it and I can add to this. So essentially, we are adding the integral output and the proportional gain; this gives you the gain so this is the error voltage. When temperature goes up this increases; correspondingly this is amplified. And it will be going minus and that will be inverted, and you get a plus and then whenever error is there this slowly charger the capacitor, and this voltage also will go towards minus and that will become plus. So, you will get addition of this voltage at this point. So both are summed up; and the summed up voltage are available at this point.

The error voltage is amplified and amplified voltage appears here. Error voltage is time integrated; and the relevant integrated voltage is available here and that is summed up with this amplified error voltage. Summed up with this, you get a total voltage at this point that is - sum of P and I will be appearing here. This we can use it to drive the heater; the heater can be driven through our standard. For example, we can have plus 15 and then we can have a heater so, that is the heater voltage so this is the circuit diagram of a PI temperature controller.

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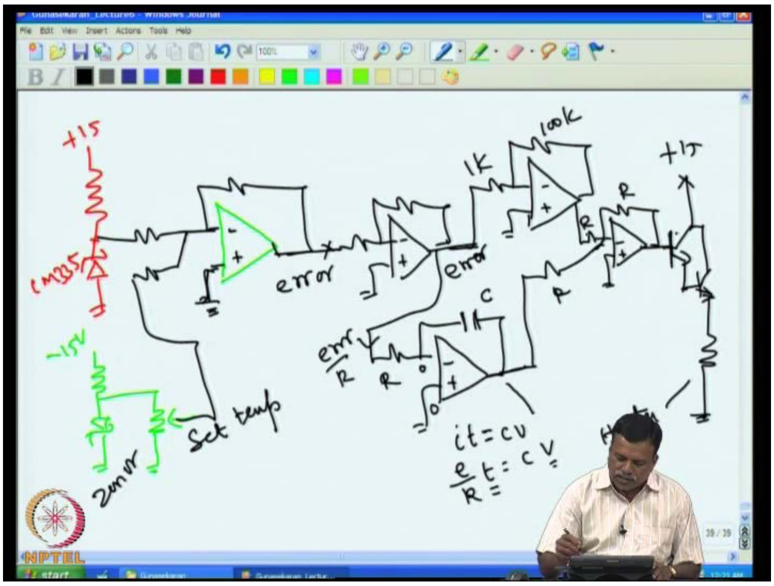

Now, see this carefully in yet another angle, how this removes the error voltage? Once if you put this integral stage, eventually what happens is you will find if you set at 80 degree; the temperature also stabilizes exactly 80 degree; you will find there is no error at all. How that is achieved? To understand this, we have to see first what happens if I remove the integrator? For example, I remove the integrator from here, this is just a proportional controller because, the difference in temperature at this point gives you error and that error voltage simply amplified; and that is inverted and comes here and drives the heater. Now if I set at say here 70 degree, you will find that temperature is not stabilizing as it will be at 68 degree. Now we see what happens if I add this integral stage.

I put the integral stage here, now if there is a output voltage here; error that actually will be adding up slowly. It is a capacitor and the resistance is here. whatever voltage is here this is 0, there will be a current through this. The current through this will be the error voltage divided by R, so the same current goes here and charges up the capacitor. Eventually, you know this voltage will be slowly going towards minus at the rate determined by this current because, i into t is equal to c into v, so you know the i that is nothing but error divided by R. Then c is fix so with time as time increases; v have to increase so only thing is it is minus. At this point it can become plus, if I give it to this inverter stage in addition to, what is coming from the proportional stage. I will put these values equal; all three equal. Whatever voltage is here that will be added with this voltage; and that will appear here. But what happens initially, morning when you switch on the system you will find that you had set this one at 70 degree; and the heater was only because this is anyway linked to this one so this is at 25 degree.

Eventually, you will have the error voltage will be high; and this is having a gain because we do not keep this 1 is to 1. We keep this one for example, I will put here 100K and 1K that means - I am giving a 100 gain per proportional stage; so you will have a high voltage here and this is anyway minus; and that becomes plus and the heater will be driving. At that time, this voltage is initially the inductor capacitor was not charged, so you will have almost 0 voltage, but since, error is there it will be slowly started increasing towards minus side and that will move towards plus side.

So what happens, if it already saturated there, would not be any change. As this increases this voltage also is supposed to increase; if it is not saturated even if it saturated there is no harm, then after sometime temperature of this would have increased. Then the error voltage will come lower and this also would have reduced. By that time, this would achieve enough voltage and you will got now contribution from this as well as from this. Suppose the error had become 0, the set temperature exactly equal to the actual temperature, then the error can become 0 and you will find no output due to this and this become zero. So then this also become 0 but that makes no current flowing through this. But, whatever charge that was stored earlier and this capacitor will remain there and the output voltage will remain there even though the error voltage is 0. That is actual advantage of this integrator, so you have the input 0 for output voltages because, the capacitor's already charged.

So, you have this output voltage - that now will be driving the heater, now that is what we wanted because with error. We need some output voltage to the heater because, heater voltage cannot be 0; if it is 0 then there would not be any heating. If there is no heating it cannot stay above ambient temperature so, that means we able to get the heater voltage without having any error.

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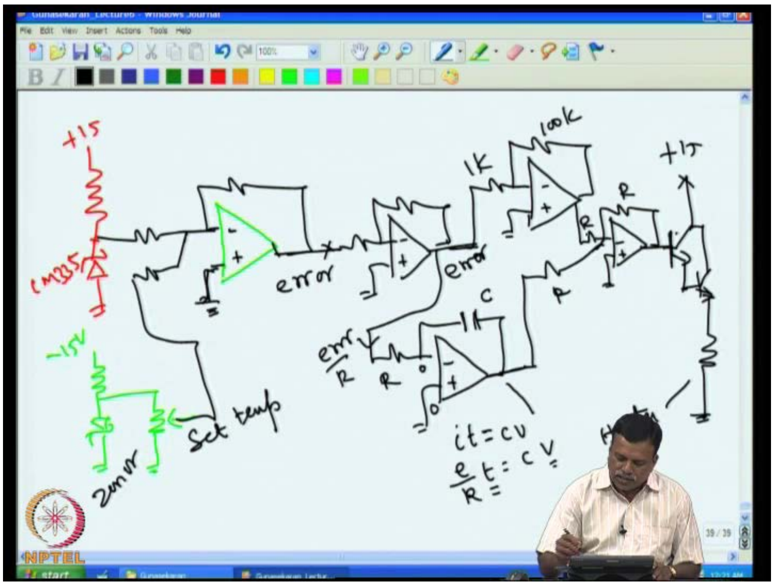

Suppose you may ask, what happens if the temperature had gone higher than the set value? Suppose, if the temperature goes higher than the set value - the error becomes minus; then the minus makes the reverse current flows that means - the capacitor will discharge and the voltage will reduce, and this voltage also will reduce. Anyway this minus actually become plus and this plus again become minus, so that again reduces this voltage.

So even if the capacitor will discharge only if the temperature exceeds the set value. If the voltage drops too low then it does not matter; if the temperature comes down again the error voltage will come. And then, you will see that, this is again charging up and the heater voltage also again increasing.

This way the integrator makes sure that, there is no error at all, in the sense - that set temperature will be exactly equal to actual temperature. This is good because, if we had the difference that is - if there is an error we had seen that this produces secondary effect in the sense; that if the ambient temperature changes then the error also changes and that creates a problem. It appears as if, the controller is slowly drifting with ambient temperature, this problem is solved by adding an integrator.

So, the integrator was a good invention but then, always we get confused because integrator is there of course, I can reduce the gain substantially because, even if the gain is lower; the error not going to be there at all because, integral action is there that will take care. But, one has to set correctly the required gain and then the required time constant for the integrator.

Now, this is an issue that is to be discussed in detail because, one may wonder why when the gain is high? The system gets into oscillation actually; we had to pick up this information from our established control theory because, what happens is in any control system we had to find, what is the electrical equivalent of a control system or in this case electrical equivalent of this temperature controller?

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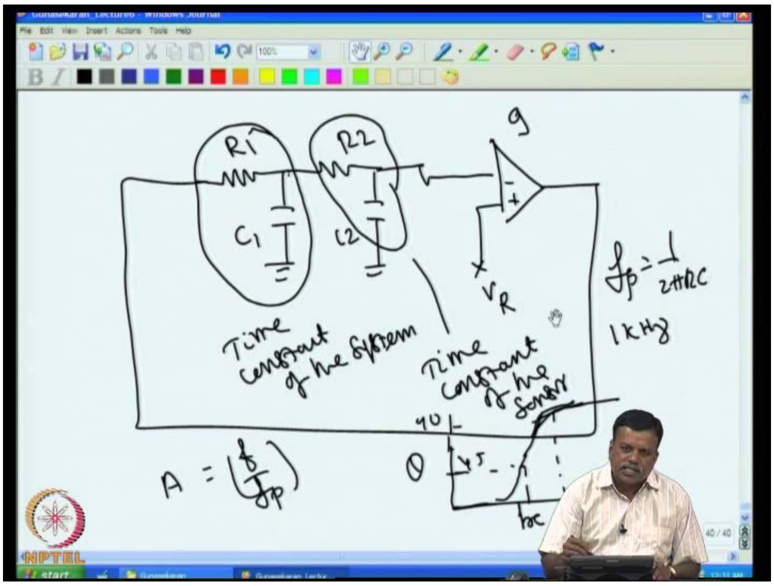

Now, I can show the electrical equivalent like this; that you have a system 1 RC then, I have another RC; R 1 C 1, R 2 C 2. Now, I put here system with some gain g with reference V, reference - where we want to set the temperature. I give it back to this. Consider a system like this here - we are modeled this R 1 C 1 as the equivalent time constant of the oven, for example, if I apply a voltage to the heater then the temperature of the oven slowly rises, now same thing happens here. If I apply voltage here then, voltage at this point slowly rises depending upon the time constant of this. So we take this is a equivalent time constant of the system.

Now take the R 2 C 2, R 2 C 2 - actually represents the time constant of the sensor. Now actually, what we have done is, we have modeled system and the sensor into the control loop using low pass filter, that is - R and C. we have realized time constant of the system; and the time constant of the sensor. So if I put for example, if I take a temperature sensor, the time constant of the sensor is roughly equal to 1 second, that is - I can always make it this RC time constant as 1 second. Similarly, is the time constant of the oven; it may be 100 seconds or 200 seconds that depends upon the system.

Now consider this case here, we have an oven and here we have a temperature sensor and then, what we are doing is we are giving temperature sensor output to the comparator or an amplifier, and then we are compare it with the reference. This is the set value, the difference between these two is amplified and amplified voltage appears here.

Now if I have a system like this, naturally, this will oscillate because when I increase this, then increase takes place with time delay and even this voltage. whatever this is and the oven that is sensed only after again sometime given by the time delay of the sensor because of that what happens that by the time it reaches the actual temperature the voltage here had already gone much higher and net result is the system will be keep oscillating many times if the gain is sufficiently large here of course if the gain is less it will not oscillate.

Now to understand that, we can look this in the whole system in a slightly different angle for example, if I take RC - this RC can give phase shift as much as 90 degree. And this RC also can give a phase shift of 90 degree at some frequency. If at some frequency, if this phase shift also 90 degree; and this phase shift also 90 degree, then total phase shift introduced by this; and introduced by this will be equal to 180 degree. And we have this controller is already having 180 degree phase shift, that means - at some frequency it is possible to have the total phase shift of 360 degree because 90 plus; 90 plus - 180 can give the phase shift of 360 degree. That means, we got a phase shift of 360 degree, that is, one condition required for the oscillator to work.

We already produced the 360 degree phase shift. Another condition satisfied for the system to oscillate is the loop gain, should be more than 1 because, we had given a gain here, some gain in this. But then, these two are actually acting as attenuators because, if I give some frequency here and some AC signal of some frequency, I say - 1 volt amplitude, then at this point, I will have only reduced voltage that means - the system works as a attenuator, and this also works at attenuator. So attenuation provided by this; and attenuation provided by this; the combined attenuation. If it is combined attenuation into this gain, and if it is take; and if it is more than 1; and if the phase shift is the entire loop phase shift is 360 degree, then the loop can oscillate.

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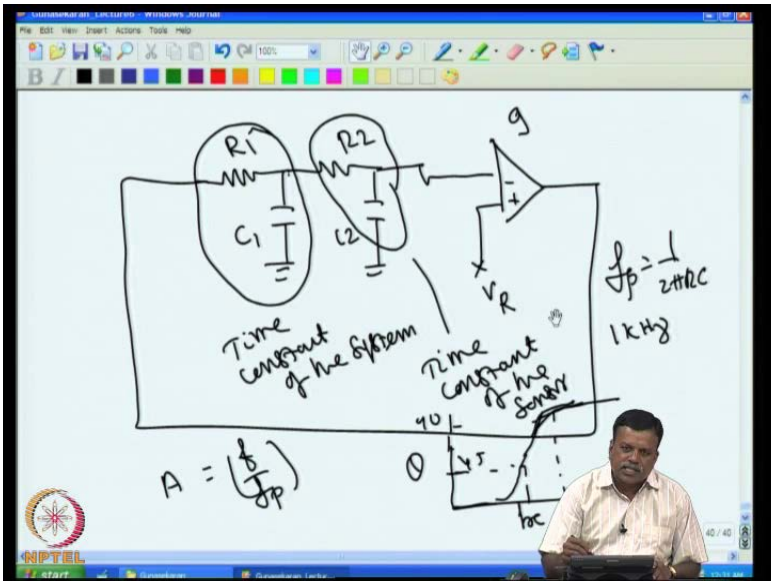

So if you do not want the loop to oscillate, we have to make sure either the phase shift is not 360 degree around the loop; or the gain is lower than what is attenuation provided by these two RC elements. If that is satisfied, then system cannot oscillate.

We know that RC time constant is a single pole filter, and this also single pole filter, so above pole frequency the attenuation provided by this is 20 DB per decay, that is it attenuation linearly increases with frequency; this attenuation also linearly increases with frequency. For example, if I take the pole frequency of this, the pole frequency is - we call f p is equal to 1 by 2 pi RC, that is, the pole frequency. If the pole frequency is, say for example - 1 kilohertz that means at 1 kilohertz, it will give you 45 degree phase shift. Then at 10 times the pole frequency - at 10 kilohertz the phase shift will become 90 degree. Because, if we plot the phase shift versus frequency, say theta versus frequency, that actually it is almost 0 degree phase shift and then at pole frequency it becomes 45 degree, that is at f p it is 45 degree, then 10 times the pole frequency. This becomes 90 degree then afterwards it almost stays there you know stabilizes there.10 times the pole frequency you will get, 10 f p the phase shift is 90 degree. We also know that, at pole frequency we will have the attenuation provided by the filter will be root 2 times, that is - if it is 1 volt; you will get 0.7 volt at pole frequency at 10 times the pole frequency. If it is 1 volt, you will get only 0.1 volt because, the amplitude also is given by the relation.

The output amplitude actually goes by again the ratio of this f by f p.

If the actual frequency is 10 times more than the pole frequency, then attenuation will be wave factor of 10 that means - if you increase the frequency, the phase shift is increasing. But the attenuation also increasing correspondingly but then, we know that sensor is having a very low time constant say, 1 second and is having a time constant of about say in this case, 100 normally with the sensor this system time constant is high. And it is must because, if the system constant is not high it will show you that it is very difficult to give higher gain.

Now the question comes, if I have a system like this how the attenuation is taking place here and then here? Then how the loop phase shift is coming around? Now, we should try to find out what is the condition that you need to avoid the system to oscillate. That is - any one of the conditions should not get satisfied. If you do not want the oscillation in the sense, that either the phase shift should not be 360 degree around the loop; or the gain should be less than 1 around the loop. If any one of them should be there if satisfied, then the system will not oscillate. Of course one easy way is - reduce the gain, if you reduce the gain then attenuation will be dominating and then the loop will not oscillate that can be done very easily.

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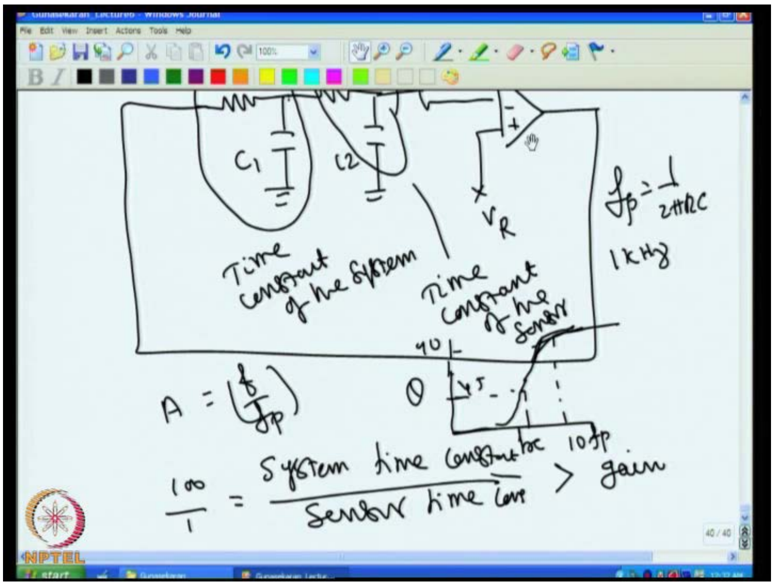

Now you can work out and see. I will show the gain for example, I find the system time constant divided by sensor time constant, I find the ratio between these two; then the ratio between these two that should be always less than the gain. It should be other way around, that is - gain should be smaller compared to this time constant. For example, if it is this system time constant is 100; and then sensor time constant is 1 second; it is 100 seconds and 1 second then the gain should be less than 100. Then system will not oscillate, this you can work out and see. Because, if this is the case, you will find that condition for oscillation will not get satisfied in terms of the loop gain.

So if one maintains this ratio, that is, the gain of this amplifier if it is less than 100 then definitely system will not oscillate at any frequency. In this case, that means - I had to make sure that, overall the actual gain given by the error amplifier is less than 100, then it will not oscillate.

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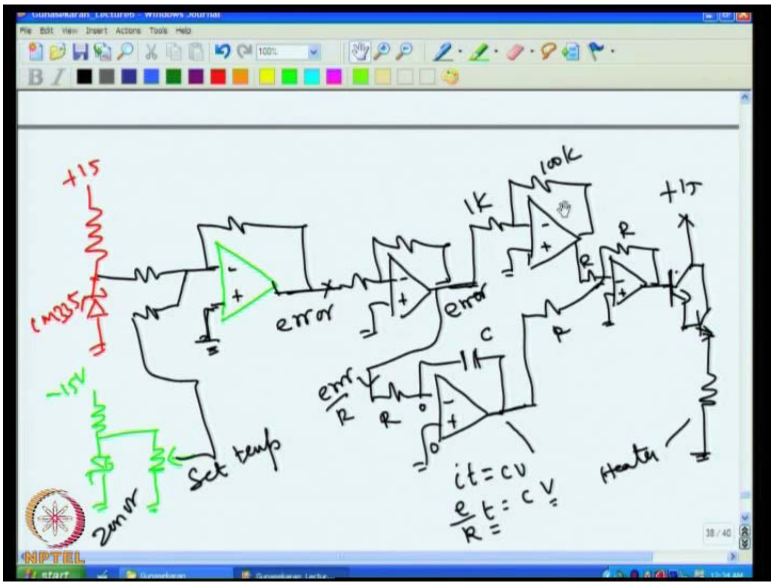

So in our PI control, what we have discussed just now? What we have to do is, I have to set the gain here that is, the gain here. What we are shown here is 100, this gain must be lower than 100 that is, that 100 is coming because, of the ratio between the system time constant and the sensor time constant, and if this gain is less than 100 then, the system will not oscillate. So normally, what is done is, we keep about 50 percent margin, so if we need gain of 100; we keep gain of 50 for proportional action then the system will not oscillate.

Now, we add the integral time constant, if we add integral time constant the gain is less. If PI proposed action was there, you would have got lot of error because of integral action, now the error also goes off and the system stabilizes without any oscillation, so the gain should be set correctly like that.

One more question comes into picture that, there is a difference between electronic gain and the system gain, what we had discussed because in the system, what we had shown here; it is actually temperature system so all the units must be in terms of temperature. So the gain that we get, what we set also has to be in terms of temperature. This is a little complicated issue; many of the textbooks actually ignored this. And then create a continuing doubt in the minds of students ever, what we have to understand is that, for example, if here is the system time constant is 100; and sensor time as 1; the gain required is not more than 100. And if I put here 100 gain, you will find the system is not working properly because the gain 100. What we have told there is a temperature gain not the electronic gain. So, we had to convert this temperature gain into electronic gain that is a must. How to convert this temperature gain into electronic gain? we will see how to do this? Because, this is very often ignored and then will end up in blaming the temperature controller.

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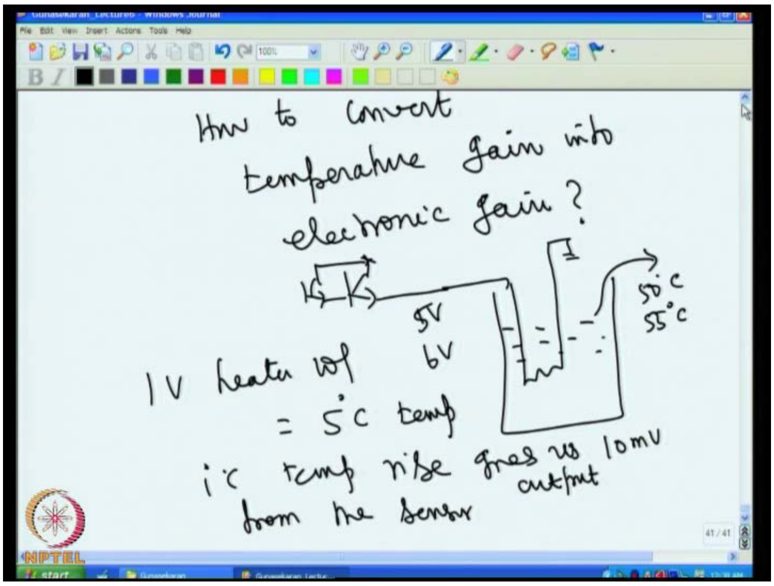

So, we should find out how to convert temperature gain to into electronic gain? Now for this, we had asked the question suppose, if I have a heater, how much voltage I have to give to raise the temperature of the oven by 1 degree? For example, if I take system like this, if I assume, this is the system and this is a heater, which was connected in our case to 15 volt. One end was connected and another end was connected to the heater driver through Darlington. We have connected like this, now, if I vary 1 volt here, then what is the temperature raise expected here? For example, 1 volt change may raise the temperature of this. Assume, in this case, the temperature goes up and stabilizes. For example, originally it is 5 volt then, temperature at this point was 50 degree. I give six volt, then temperature will go little higher than this and stabilize because, assume that it is 55 degree. That means - for every 1 volt that is, at 55 degree it went and stabilized. Where 55 degree what the hit coming in is equal to hit going out that means 1 volt change here gives you, 5 degree temperature change that means - 1 volt heater voltage equal to 5 degree temperature raise, that means - if I get 1 volt at the heater, then its equivalently I am having 5 degree temperature raise.

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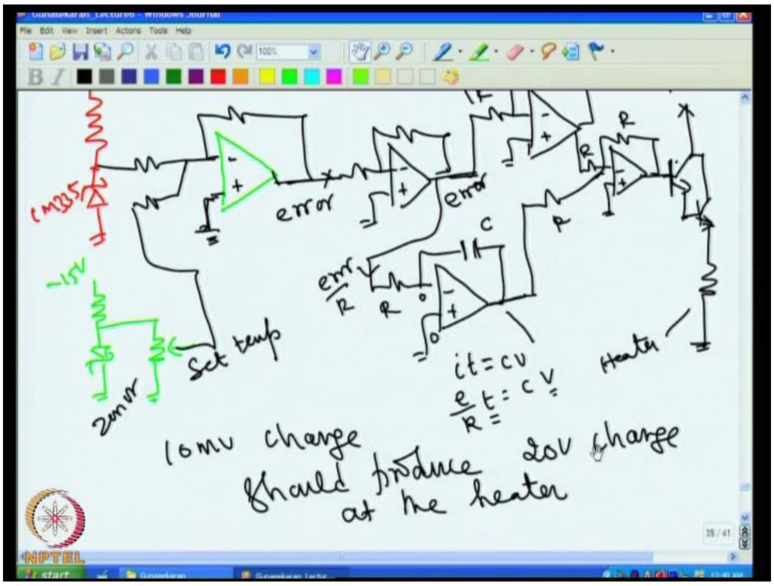

Now, 1 degree temperature raise gives us 10 millivolt output from the sensor, that means - if 10 by 1 degree change occurs then, I will have 10 millivolt change in the error voltage because, if you go back our circuit and see, you know 1 degree change here will give us 10 millivolt change here. Now 10 millivolt change, if the temperature gain as supposed to be 100, because, we want a temperature gain 100. That means, 1 degree change in temperature should produce voltage change here, corresponding to 100 degree that means - 1 degree change should give me 20 volt change because, 1 voltage change here we had set is producing 5 degree temperature change.

That means, to change 100 degree temperature, I need to have 20 volt change. That means, if at this point, if 20 volt change occurs we know that the temperature will change by 100 degree C, that is, we had find out experimentally that is no other go. So if 100 degree change have to occur, then 20 volt change have to take place with 10 milli volt change. So what actually works out is - 10 milli volt change should produce 20 volt change at the heater. Because, 20 volt change at the heater will change 100 degree temperature change. But, we know one degree change will give us 10 milli volt, by this sensor if I want 100 gain for the temperature gain of 100. Then 1 degree change should produce a 100 degree change voltages, corresponding to 100 degree change. That means, 10 milli volt change should produce 20 volt change, this works out 2000 gain so that means electronic gain required is 2000.

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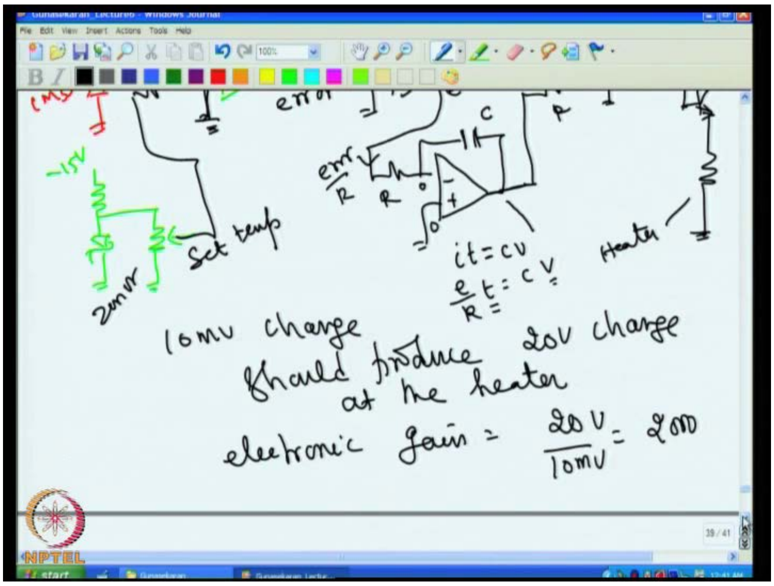

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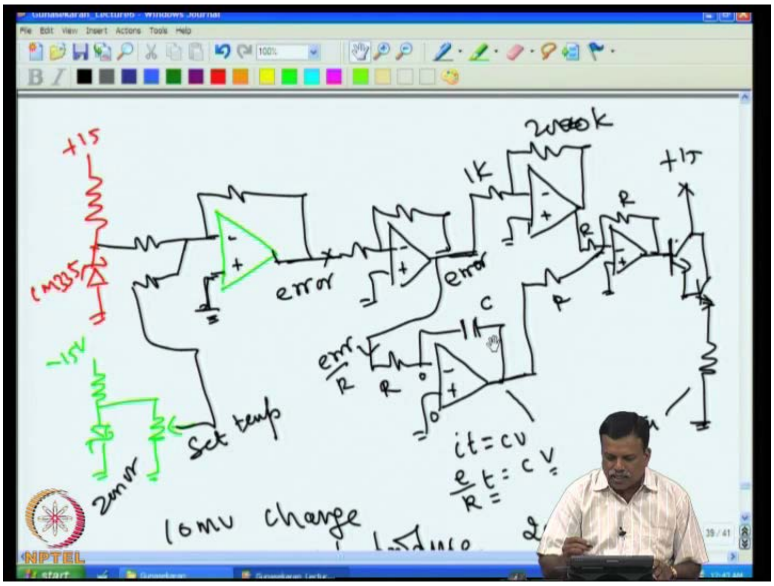

So if you work out this, the required electronic gain is 20 volt divided by 10 milli volt that is equal to 2000. Essentially speaking, temperature gain of 100 is equal to electronic gain of 2000, so I have to have the gain setting to be done, that is the resistance change. The resistance what I have to set here is, not 1 and 100K. I have to make it for example, 2000 gain, here I should put 1K and 2000K that is to make. If I want I can put this one in two stages, which we see later how to get large gain instead of getting large gain? One single stage is better to get large gain in more than one stage, that gives the better result. This we see later, but what is required is electronic gain requirement is 2000.

So, once you do that then the system will stabilize without getting into assigned. Actually, what you need is, gain of less than 2000 is required so what actually done not this one . We have to put in this case, 2000K so 2000K that will give you 2000 electronic gain and that will correspond to 100 gain of temperature, same type of scaling have to be done. Even for integral time constant sitting also, because the voltage levels are different. So, if we had to set the integral time constant, we also had set only in terms of temperature unit not in terms of electronic unit. This I leave to you to think for some time still my next class. Next class, I will explain you, how will you do this? Because you can work out and see, mentally you can think how to convert this time constant electronic time constant from the temperature time constant? That we are expecting because, we can also show you from the control theory that the time constant of this integrator should be equal to system time constant. If you do not want system to oscillate that means - I had to put RC equivalent to system time constant, this case will supposed to be 100 seconds for the 100 second means - we have to also consider same type of scaling that we are used in the case of temperature.

So one can set this R and C after scaling then only it will work. I will not explain in this class, I will explain how to do this in the next class because, this kind of scaling is not done invariably; and it is ignored one in almost all the text books done. And then invariably find when you design the controller it gets into lot of oscillation, and then lot of trial and error is done and then we try to use this. Now we see how can we add a differentiator? and what is the necessity to add a differentiator to make it? A PID temperature controller is the work hours in the industry, so it is essential we try to understand how to make a PID temperature controller?

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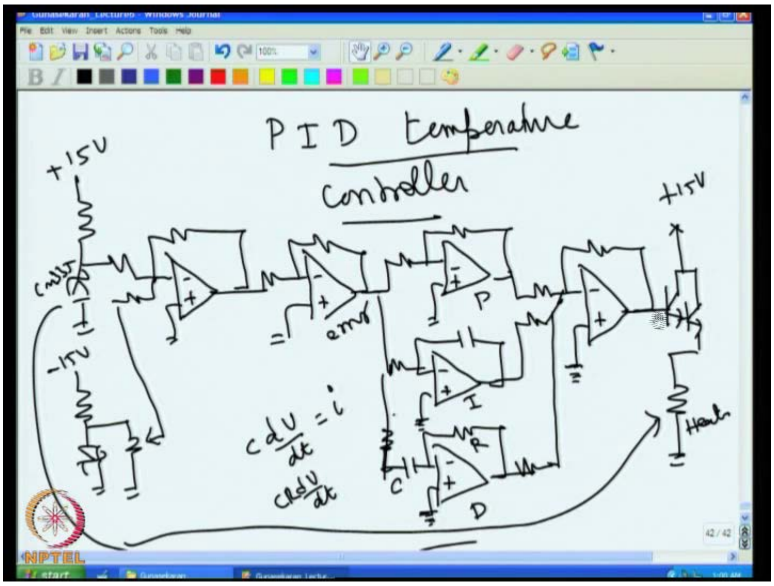

So what you do is, that we now see how to make a proportional integral differential so called PID temperature controller? Now, what can be done is, we can use the same logic just we add the differentiator stage then, this becomes a PID temperature controller. Let me redraw quickly the entire circuit, so what we had done was we had in the earlier case. we had our temperature sensor that was given to. I think it was given to plus 15 then LM335, then we had minus 15 is a reference voltage that is - a set value. Then we add the difference between these two, the error between the set value and the actual value you have got here. That is, the error voltage and then earlier case, when the temperature goes up this plus is going up, and then this will be going minus. So remove that, we are inverted this so that also can be done. Now, you got an error voltage here so, when temperature goes up this also will be going up. Then, we add proportional all three stages here that is, PID stage first proportional stage.

So, I set the required electronic gain here, then let me add the integral action here Integrator error voltage drive this, Now, I add differentiator here, so we have a differentiator. What you do is, we put the capacitor, then the resistance , so you got a proportional stage; the integral stage; differentiator stage. So, these three are - you have done it then you sum all these three like earlier, we had integrated summed only P and I. Now, we sum all these three, so you got the summed up voltage that should drive the heater. Now, that heater drive can be put now. I connect the heater so you have heater here, of course this heater is actually physically coupled to the sensor. This is physically kept here, this is driving the oven and that sensor is connected here. So, that it acts as a temperature controller because, that feedback automatically takes as temperature sensing is done. That is, how the feedback is taking place and then the system? I will try to stabilize at the set value that is our aim of this PID controller.

So if we see our earlier discussions that we had a proportional controller wherein we had only this stage and these two were not there. Then, we had added integral action that time, we had only these two, and this was not there now. We add a differentiator stage, we add it here in addition to this, and then it becomes a PID temperature controller. All these outputs are summed up at this point to produce the net voltage and that is the one which drives the heater. Now the question comes, why you need a differentiator? Because earlier we said, we need an integrator because proportional controller alone. If it is there it is having an error voltage; if there is an error voltage then system is not stabilizing at the set value.

So, we set we will add an integrator by adding integrator we have removed the error voltage. So, even if you give a low gain also there is no problem because error is not there. If error is not there then, if ambient temperature changes it will not make the system to drift, which we have already explained. So, a proportional integral action is enough to get a good stability. If the system oscillates, all that we can do is - we can reduce the gain so that, if the gain is less; system will not going to oscillate. That we had explained earlier by showing, what is the necessary condition for the system to oscillate.

So once that is not satisfied, the system will not oscillate, that we can achieve by reducing the gain of the proportional stage. It looks see proportional integral temperature controller is enough, and there is no reason why one have to go for differentiator? The requirement our differentiator comes depending upon the speed of the response.

Now there are two issues which are coming now, by adding an integrator. We have removed the error, but then the system, the integral time constant is kept equal to system time constant. Because of that what happen, the output of the integrator changes very slowly. And we already reduced the proportional gain to avoid the oscillation, so the output for the proportional stage also low only.

So to get enough voltage for the heater to raise; we have to wait for quite a long time because, this works very slowly. Probably for system like temperature controller you do not need differentiator, but there may be a case we are controlling a faster system, for example, we are controlling a position of a mechanical system using a motor. In that case, if I want to control the position instead of temperature then, I will give a voltage corresponding to position here. And then, I will get a position feedback and then probably I will make an arrangement to drive a motor.. In that case what happens - if the differentiator varies slowly then system become very sluggish, the system will not go to a set value quickly and then it will take long time. So to avoid that it is essential, that we have to have a differentiator this makes a system very fast.

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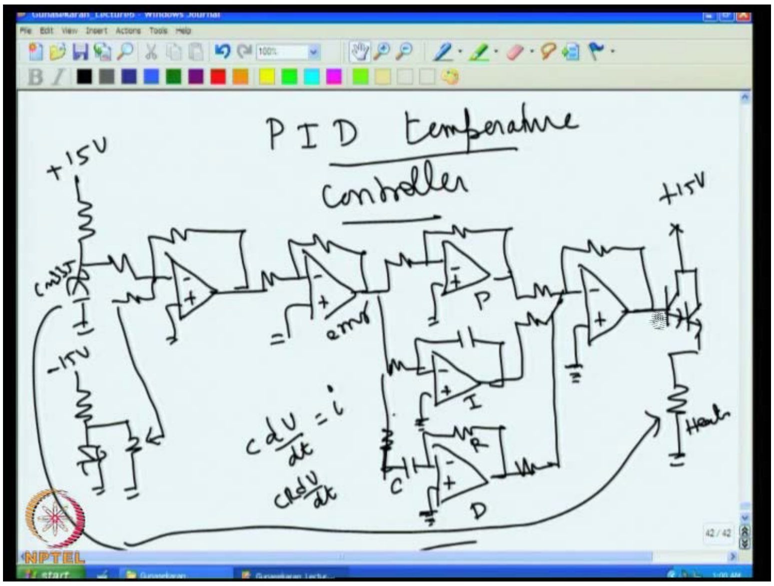

Then there is another advantage with the differentiator. Suppose, if I make the differentiator time constant is equal to one of the time constant which we had discussed because, we said this temperature control system is having two time constant - one is system time constant; another one is a sensor time constant. Assume that, I make the sensor time constant equal to differentiator time constant. If these two time constants are matched, then for the system it appears as if only one time constant is there. That is system time constant alone is there, and the other time constant is canceled by this. That is good because, if I have only one time constant in the system or only one delay in the system, then maximum phase shift that we can get would be only 90 degree. Because you know - 1 RC can produce only 90 degree phase shift, not more than that. With 90 degree phase shift, system will not oscillate even if the gain is higher and that is good for us. Because, we do not want the system to oscillate, so it is always advantageous adding a differentiator. And that too, if I match the differentiator to one of the time constant, even one pole also get canceled and oscillation of the system can be avoided.

So differentiator may give us two advantages, one is - it makes the system fast; other one is the... If I match it to one pole, then the system oscillation also can go away. So what we do is, we match this one of the time constant.

Before that, let us try to understand, how the electronically the differentiator works and what really makes this? You know the differentiator is an ideal element in this case, because many times we will use only P and D is enough even integrator is not necessary. If I can give large gain to the system, even I can increase the system gain. if I add D because I had removed one pole, with only one pole system will not oscillate even if I give a gain.

So let us try to understand how the system works? For example, if the temperature error voltage changes; the error voltage increases here. We will see the increasing voltage will produce a changing voltage at this point. what is the change in voltage, because this is capacitor C; this is R; so current through the capacitor is C into dv by dt, that is - the current through the capacitor, so voltage at the output will be C into dv by dt into R, so that becomes CR into dv by dt. Whereas, dv by dt is the rate of change of this voltage or rate of change of actually the temperature here.

So temperature change produce a voltage change here; and the voltage that is available at this point, depends upon the rate of change, so if the temperature change is fast or if it is a mechanical system, where I am dealing with the positioning. If the system is moving fast then this voltage also will be changing fast, that will produce a large changing voltage because, if dv by dt is more - you will get large voltage change, and large voltage change will occur here on the system that means - if the system is faster, then correction also taking place faster. Other way around, if the error is changing fast, then correction also changing fast and system will stabilize quickly.

So that way the differentiator helps our system to stabilize fast and invariably we match this differentiator time constant equal to sensor time constant, because sensor time constant will be the slowest because, normally you know, we try to make a sensor which is fast responding because fast responding is required, then only we get large ratio between system time constant and temperature sensor time constant. So normally, system time constant is larger and sensor time constant is smaller.

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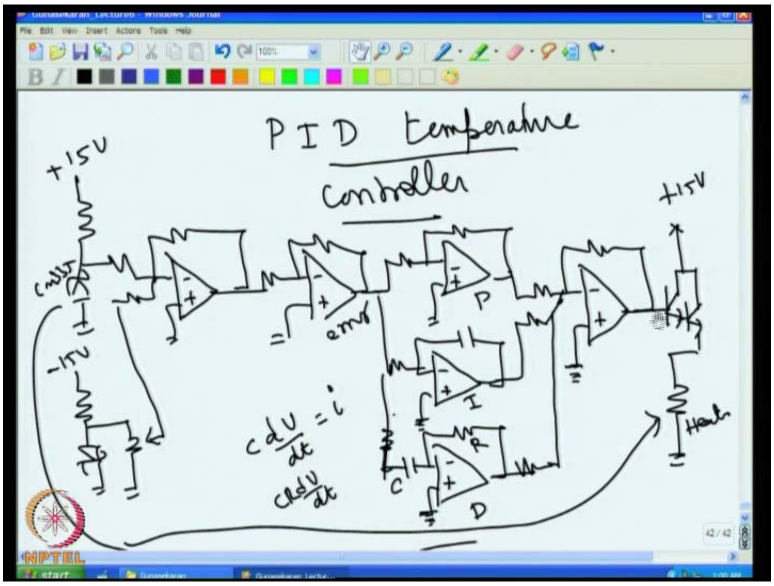

So we try to match the smallest time constant to the differentiator, this is mainly done to avoid the noise pick up. Because as we said, if the voltage change occurs here at this point. And that changing voltage produces a changing voltage here, we are using a capacitor and if I had to have a large differentiator then I have to use large C here. If large C is used, then you see CR into dv by dt is the output voltage, and if large C is used then even small change here will produce a large change in voltage and that can saturate, and we know that system is always having a noise.

So if I put large C, even a low frequency noise itself can produce a large voltage change and the system will be driven with the error; not with the noise; not with the error that is not a desirable one. So we do not want C respond for the noise, it should respond only for the error but you know any change, whether it is a noise or the error that cannot be recognized by this capacitor. So what we do is, we will take C smaller so that the noise response is less.

So if C is smaller, the noise response going to be smaller, so that is why we are selecting lowest time constant. For this in addition to that, we also do one more protection that we do not want the system to respond all the way for all the frequencies. I can make it that there is a very low frequency change and that actually will not produce too large current flow, that current flow will be limited by add this resistance.

So we can add a small resistance relative to this R such that, we will not get too large gain for very high frequency noise because for example, in the temperature controller the change will be very small even in a normal system, whatever noise is there in the electronic system, that noise frequency will be much higher than the system error frequency. In that case by adding this resistance, the high frequency noise will not produce a large output and that makes the system not noise driven, that will make a system to error driven.

We have to have a resistance to limit the noise response, so that way the PID temperature controller works satisfactory. Of course I ask you to work out, how to scale the integral time constant and similarly the differential time constant to the temperature scale? The electronic time constants the differentiator time constant, and the integral time constant is the one which actually drives. But, that has no relevance to the temperature time constant, so one has to scale it up the same way as what I had shown in the example. For proportional gain time constants only should be used here not the temperature time constant that will get as I had explained.

This I can explain you later, so mainly I am doing it so that you will think about this and then come back in the next class, so that you have some thinking to do at home. of course now, we see how to make a heater drive for different systems because, here we had shown, if I have a heater like this and the heater requirement is less than 15 volt I can directly give like this and drive. But then, you rarely find that you have a heater which needs less than 15 volt. Sometimes, you may need a heater which is 1 kilowatt or 2 kilowatt or even 100 watt; 200 watt like that. So, if the heater voltage requirement is more than 15 volt, then this circuit has to be changed this is not enough. It will not work, for example - you may think that many I had seen the many boys doing the same mistake.

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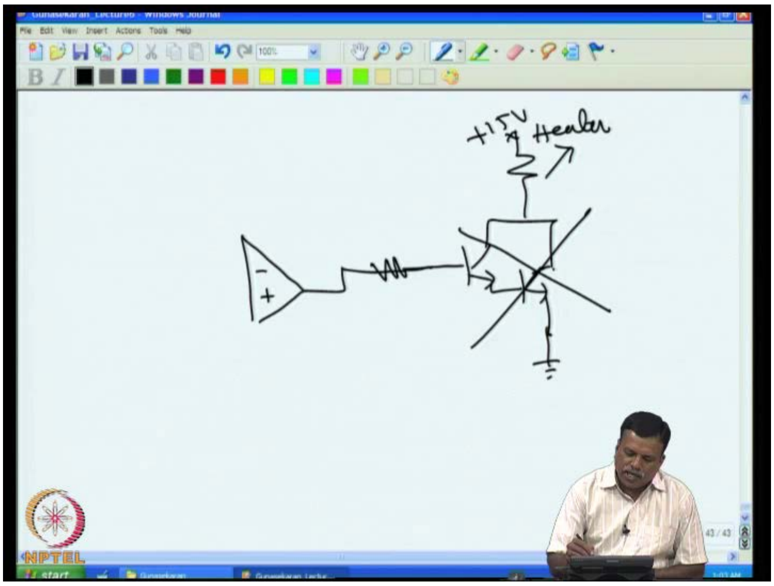

For example, if the heater voltage is 100 volt, if I connect the heater like this, I put a Darlington pair I will connect this one to ground, then connect the heater here plus 15 volt. This is heater and then this is our output driver, and the output of that is given to this of course there is series resistance.

Now if I connect like this, then this will not act as a proportional controller because, we need whatever voltage change that is occurring, at this point should produce corresponding voltage change across the heater. Then only the proportional controller action will work, proportional controller is not acting well then obviously integral and differential adding also will not do anything because, in this case for example, small change in voltage here will almost produce a large change in voltage here. In fact you have a gain here and then we also find once the voltage goes at this point more than 1.2 volt, you will find that it is completely switched on and will act like a on off controller. And the proportional controller action will be completely lost.

So, this circuit should not use this for PID controller or for proportional controller for that matter. So if I want you know heater voltage more than 100, or higher than 15, then what is that we can do so? What we can be done is, we have to make sure the voltage change here produces linear voltage change at this point, of course one simplest thing that can be done is, we can add a resistance here and then we can have a scaled resistance at the collector; or we can use this voltage as a reference and then using that as a reference, we can increase the voltage and then drive the heater to a higher voltage. All these things can be done, that we do it in the next class. I also ask you to work out some of the issues related to this, and come prepared for the next class because, driving the heater is another essential thing that is required.

what you do is, you can think of how to get a proportional gain from an electronic proportional gain from the temperature gain; electronic integral time constant from the temperature integral time constant; differential time constant also to be converted to electronic time constant by scaling?

So, these things you have to look at it and then come prepared for the next class. Similarly see how to drive different heater; higher voltage heater and so on using different circuits? These things I will you explain you in the next class.