Advanced Control Systems

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Module No. # 02

Frequency Domain Based Identification

Lecture No. # 04.

On-Line Identification of Plant Dynamics

Welcome to lecture titled online identification of plant dynamics. In our earlier lecture, we have seen the drawbacks associated with offline identification and control schemes. In this lecture, we shall discuss about three types of online identification and control schemes to overcome the drawbacks associated with offline identification schemes. This fullness and limitations of the schemes will be also presented with the help of a number of simulation studies.

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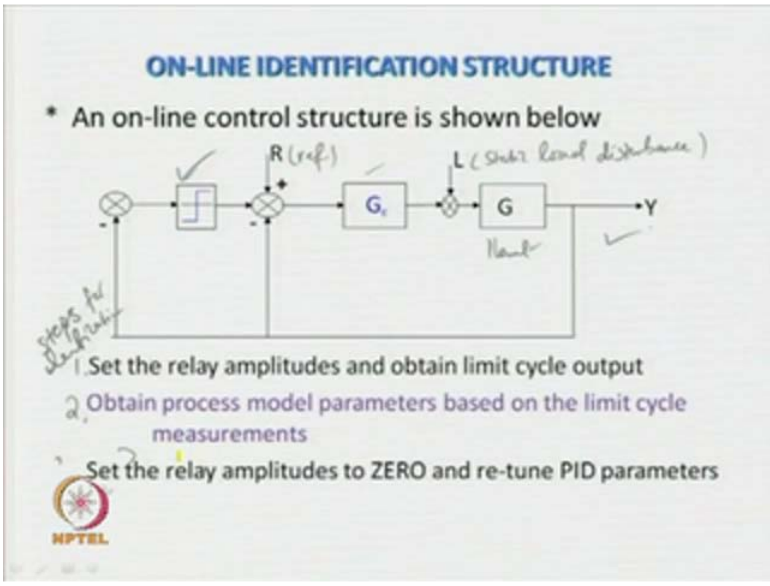

So, this is a simple online control structure which has got a relay along with a feed forward controller at the plant, in the forward path. In this scheme, to identify the features of or the dynamic model of the plant, relay amplitudes are set to some non zero values, then limit cycle is induced and based on the measurements made on the output the parameters of the controllers are set. R is the reference input and L is the static load disturbance, so whenever degradation in performance of the closed loop system is observed, relay of the tuning is invoked.

So, the steps for the online identification and controller tuning are set the relay amplitudes and obtain limit cycle output, so this this is falling under the steps for identification. First, is the relay amplitudes are set and limit cycle oscillations are obtained. Second, make the measurements of the limit cycle parameters and based on that the controller parameters are set. So, the step for the controller tuning is like this, so this is how online identification is done. Why we call this structure as the online identification structure? The relay is always there in the loop, whenever the relay setting is zero, then we have got the normal closed loop control system and when the relay amplitudes are non zero, at that time we have got the closed loop control system added with one relay dynamics. So, we basically get one online identification structure with this arrangement.

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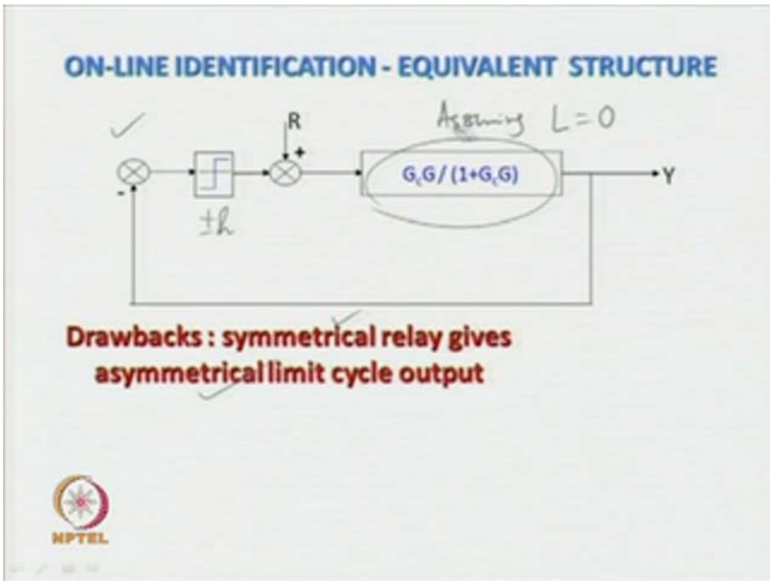

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Now, what are the drawbacks of this scheme, why we are not happy with this one? If we look at carefully the equivalent structure of the online identification scheme, then the equivalent structure can be drawn in this fashion. Of course, assuming assuming the static load disturbance L to be zero, so when this L is equal to zero, at that time the online control structure can equivalently be represented by this structure. In this structure, the relays is a closed loop system having transfer function G c G upon one plus G c G.

What is the drawback of this scheme? The major drawback of this scheme is that, symmetrical relay results in asymmetrical limit cycle output. Although we will have one symmetrical relay with amplitude say plus minus H, the output of the closed loop system, relay control systems may not be symmetrical. So, the output could could be like this, so we call this output as asymmetrical limit cycle output. Why that is happening? If we carefully observe the contribution made by the reference input to the relay output, then we can make out the type of signal we will have over here, the type of input signal to the closed loop system dynamics.

When, suppose let us for a case study, let us take R is equal to 0.5, let the reference input be unit step upon magnitude 0.5 and let the relay amplitudes be, let the relay amplitudes be plus minus 1, in that case we have got 1 here and minus 1 here and R is equal to 0.5. Then, definitely the reference input will introduce a symmetricity at the input to the closed loop system, what type of input signal we will have over here? We will have an input of the form T, this is the relay output, relay output, so we will have something like this and so on.

So, the magnitude here will be 1.5 and the bottom one will minus 0.5, so this is how we will get an asymmetrical input to the closed loop system and the consequent output from the closed loop system also will be asymmetrical. Why that is happening? When R is equal to 0, what type of input we will get? The input will be, when R will be 0 and then in that case, it will be 1s n symmetrical input to the closed loop system. So, the asymmetricity is contributed by the asymmetricity is contributed by basically the reference input.

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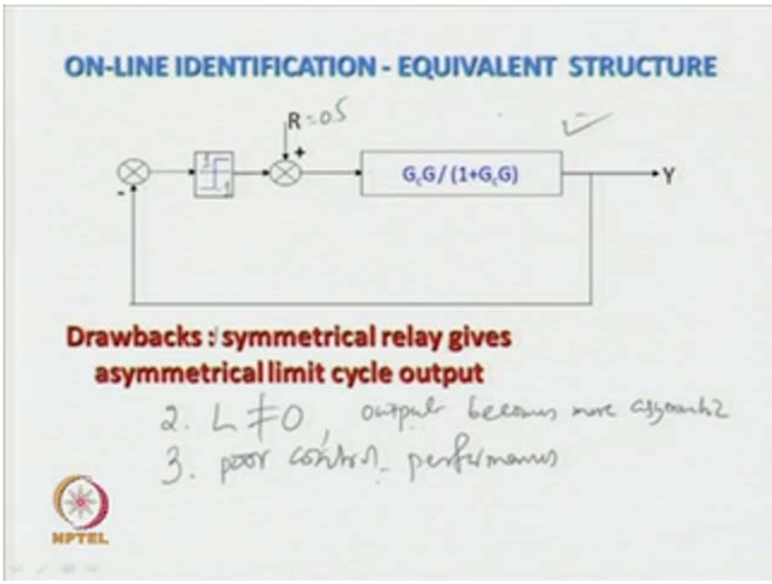

So, this is one of the major drawbacks we have associated with the online identification scheme we are discussing at present, but other drawbacks the scheme might have. Assuming the load static load disturbance to be 0, we have got this equivalent structure, but when the static load disturbance is not 0, when L is not 0, then it further compounds the problem, that means more asymmetric output may be obtained from the closed loop system, any other drawback we have? So, when we have got L is not equal to 0, in that case, the limit cycle output becomes more asymmetric.

Identification is subjected to inaccuracy resulting in poor control performances, poor control performances why we are we are getting poor control performances, because we are not able to get the exact dynamics or true dynamics of the plant or process. So, without fact full representation of the dynamics of the process, we may have a controller which is poorly tuned and the consequent result will be that we may get poor time domain or frequency domain closed loop performances from the control system.

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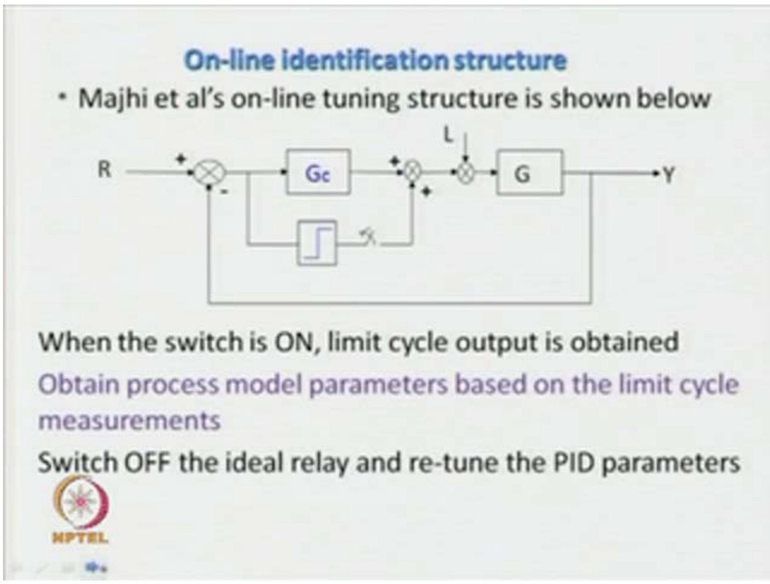

To overcome that we shall consider one more, online tuning structure proposed by majhi et al. Then, in that, in this structure, the relay is connected in parallel with the controller, so a relay is connected in parallel with the controller Gc and this is the simple control structure we have, where the relay is connected in parallel with the controller in the feed forward path and we have the closed loop system, relay control system.

So, the steps for online identification would be when the relay is on limit cycle, output is obtained. So, when we switch on the relay, we get the limit cycle output, then we obtain the process model parameters based on the measurements made on the limit cycle output and subsequently we switch off the ideal relay and retune the controller parameter. So, these are the steps, one, two, three three steps involved in this online identification and tuning scheme. What is the beauty of this scheme? The controller remains in loop throughout the operation of the closed loop system, whenever we wish to update the parameters of the controller, at at that time only the relay amplitudes are set to some non zero values and then we get limit cycle output. And consequently, we based on the limit cycle output measurements, we identify the process model or plant dynamics, transfer function model and based on the model parameters, controller parameters are set.

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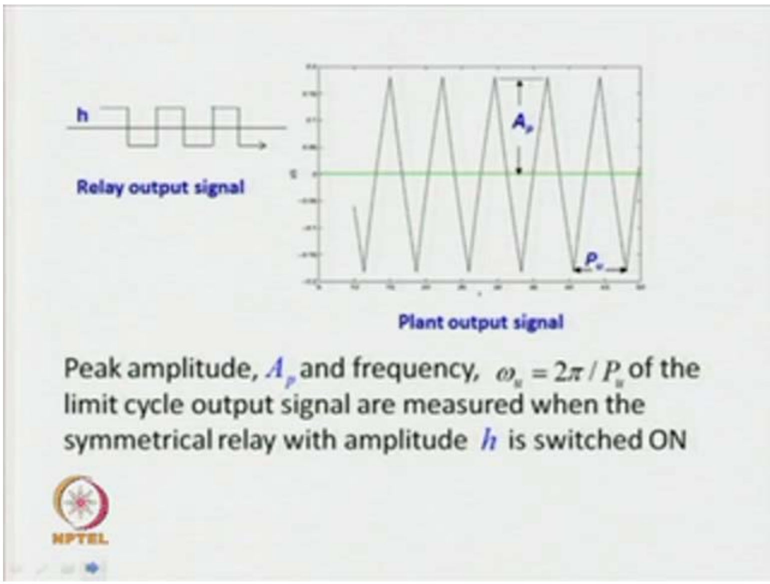

So, when we have the relay in the loop, the relay output signal will be like this, the relay output signal will be symmetrical, why that is so that we shall see in our subsequent analysis why do we get symmetrical relay output signal in spite of the presence of the controller in the loop.

When the relay output signal assumes this form, then the plant output signal becomes symmetrical and it is easy to measure the quantities like peak amplitude and time period, ultimate time period of the output signal using peak detectors and zero crossing detectors. So, the peak amplitude is now A p and the angular frequency of the signal is omega u, which is equal to now 2 P i upon P u.

When the symmetrical relay is employed, which has got the amplitudes plus minus h is switched on, so when the relay is switched on, we are expected to get some typical output of this form and typical input to the process will be of this form.

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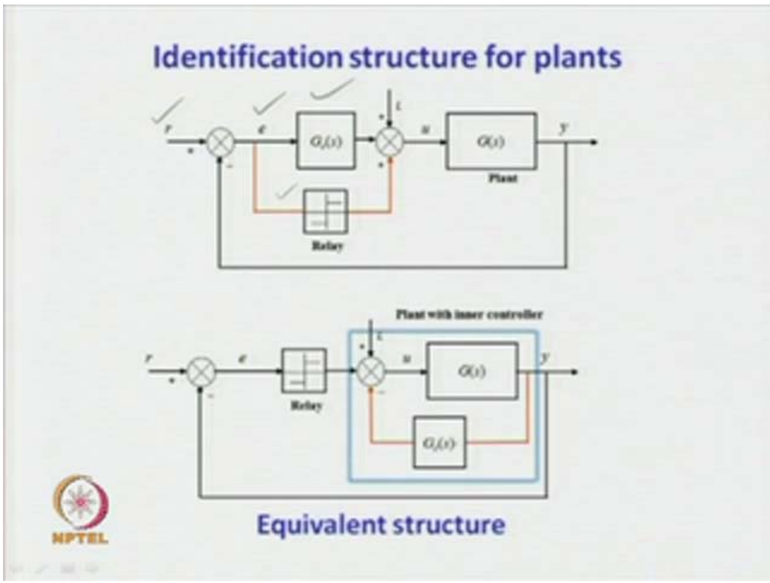

Identification structure; so, let us go back to the identification, why we are getting symmetrical limit cycle output from the new online identification scheme? To understand that let us consider the block diagram once more. R is the reference input, E is the any any error signal to the controller and also E is the error signal to the symmetric relay.

Now, when we have got the relay in parallel with the PID controller or the controller G c S, then in that case, the equivalent diagram or structure of the same can be drawn in this form. So, the equivalent representation of the identification scheme is given below, where we see that the relays is basically the plant with the controller connected in this fashion. So, the relay is subjected to now the plant with inner controller G c S and that is the prime controller we have in the system, but with this arrangement effectively all the load disturbance is present, we are not skipping anything out, in spite of that what we get the relay experiences, the closed loop system in this fashion.

So, what is the beauty of this scheme is that when the process dynamics is something odd like it possess process dynamics, possess unstable characteristics or integrating characteristics, in that case, G c can help us, come to our rescue, which can stabilize and thus enable enabling us to get some stable limit cycle output from the scheme. So, although the the relay is connected in parallel with the controller, the relays is basically a process connected with an inner controller G c S and G c S helps in relocating the poles of the open loop unstable original process G s and enables us to get symmetrical limit cycle output. So, this is the beauty of the scheme that is introduced now, next we shall see the type of limit cycle signals we obtain from different type of processes.

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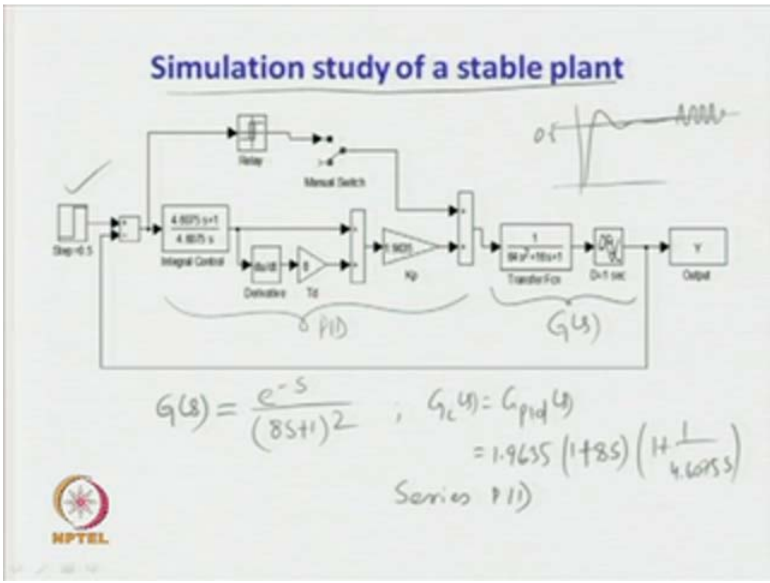

Let us consider the simulation study of a stable plant. The stable plant G s is now e to the power minus s upon 8 s plus 1 square, so this is our G s, now we have a kit forward controller, a PID controller, which is given as G c s is equal to G pid s is equal to now 1.9635 times 1 plus 8 s times 1 plus 1 upon 4.6075 s. So, we have got a series PID controller, series PID controller in the loop. How the identification is carried on?

Assuming that we have some default controller of this value controller G c s or G pid s, we shall have an output from the system time response output for any reference state input, signal of magnitude 0.5 h of the form like this. So, this is what we expect from the closed loop system when the controller is present in the loop. When the relay is connected, now when the relay is connected, then we will have limit cycle output signal and when the relay is withdrawn or disconnected, then again we will go back to the steady state condition, this is what ideally we should have from the scheme, when the simulation is drawn, then definitely we should get a time response of that form.

Now, when the relay is switched on, limit cycle output is induced after obtaining the limit cycle output for about three stable periods of output, then the relay is switched off, because after that we need to make the measurements and after making the measurements, we get the dynamic model of the process and based on the dynamic model parameters of the process, the controller parameters are updated, that is how identification and tuning is done online.

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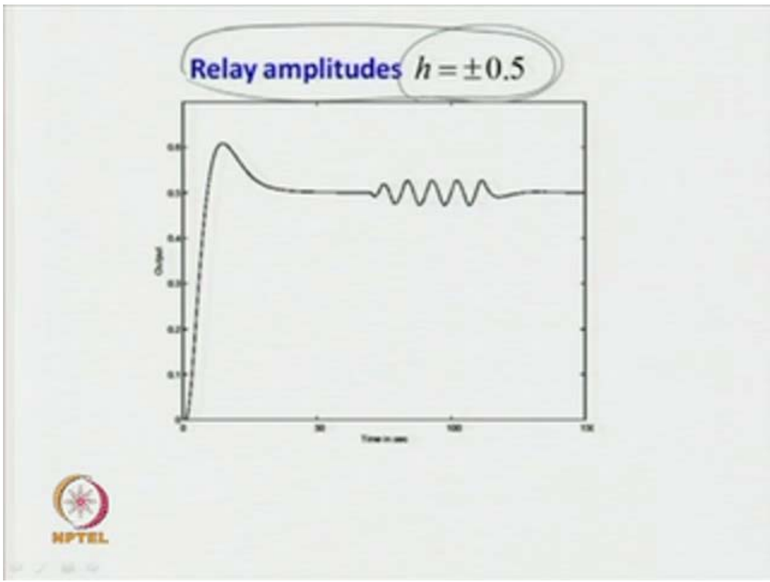

Let us see the simulation result we get from this scheme. So, when this is run with a relay setting of, relay amplitudes of h equal to plus minus 0.5, we get limit cycle output signal of this form, prior to that we have got the steady state response, we have got the dynamic response or tangent response as well as the steady state response of the system in response to the reference input of magnitude 0.5. So, when the relay is switched on at about 65 seconds, so when the relay is switched on at about 65 seconds, at that time, the output of the closed loop system become oscillatory, relay height is chosen such that the output does not overshoot or undershoot by large magnitudes, then the relay is switched off at about 105 seconds.

So, at about 105 seconds or so, 105 seconds, the relay is switched off and we come back to the normal operating mode of the closed loop system. So, this is the typical output signal we get with the reference input of magnitude 0.5 and relay amplitudes of magnitude plus minus 0.5. So, what we observe from here, we get symmetrical limit cycle output signal, so if I draw correctly, then I will definitely get the symmetrical limit cycle output signal and that is the beauty of this scheme, that in spite of the presence of the reference input the output limit cycle output is symmetrical.

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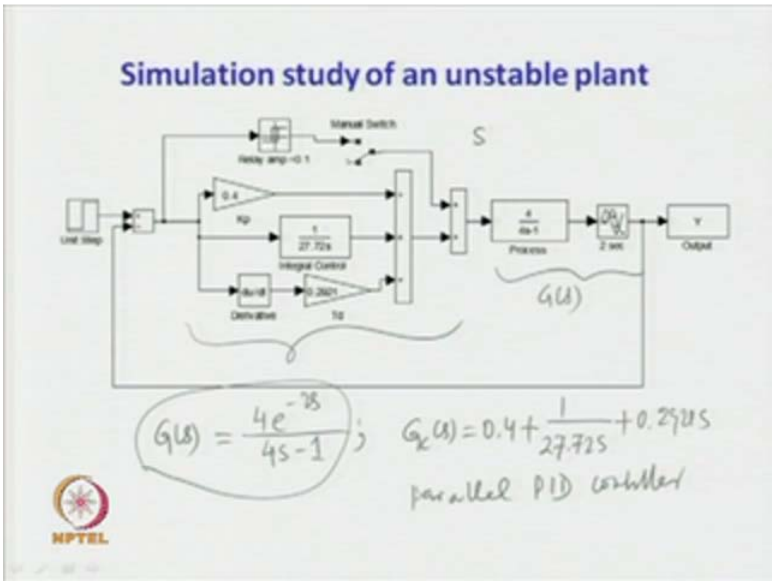

Let us go to the simulation study of an unstable plant. In the second case, we have got the plant dynamics G s as 4 e to the power minus 2 s upon 4 s minus 1, so we have got an open loop unstable process of first order for the simulation study. Next, the controller dynamics can be given by G c s is equal to 0.4 plus 1 upon 27.72 s plus 0.2921 s. So, we have got a parallel PID controller in the loop, like the previous case, we have not considered the static load disturbance, in the earlier case also we have not consider the static load disturbance.

So, L is assumed to be 0, similarly in this study also the static load disturbance, static load disturbance L is equal to 0. So, in the absence of static load disturbance, the open loop unstable process will give a time response of this form when no relay is in action. So, when the relay is switched off we get a dynamic response of the closed loop system of this form. So, we are we are getting a poor time response of the system as expected, because we are considering an difficult in unstable process or plant and therefore, the response is not satisfactory, but when the relay is switched on at time t equal to 100 seconds.

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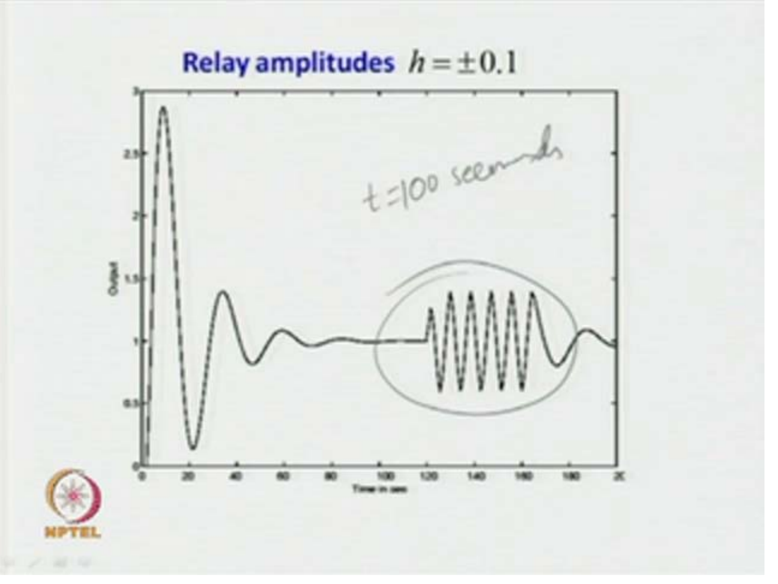

So, when the relay is switched on at time t equal to 100 seconds, then the limit cycle output takes place, the relay induces limit cycle output. And when the relay is switched off at about 160 seconds, so at time t equal to 160 seconds, at about 160 seconds, the relay is switched off. So, asked initially, switch on the relay at about time time t equal to 100 seconds and switch off the relay at time t equal to 160 seconds, in that case we get the output of this form.

Again making measurements on this limit cycle output, since the limit cycle output is symmetrical, we can make measurements of a p and t u and based on that the controller parameters can be set based on the models we obtain using a p and t u. Now, this limit cycle is symmetrically if you draw a line like this, which is of magnitude unity, then we see that apparently the output signal we see is nothing but a symmetrical output signal. So, this symmetrical output signal is obtained with the relay settings of h equal to plus minus 1.

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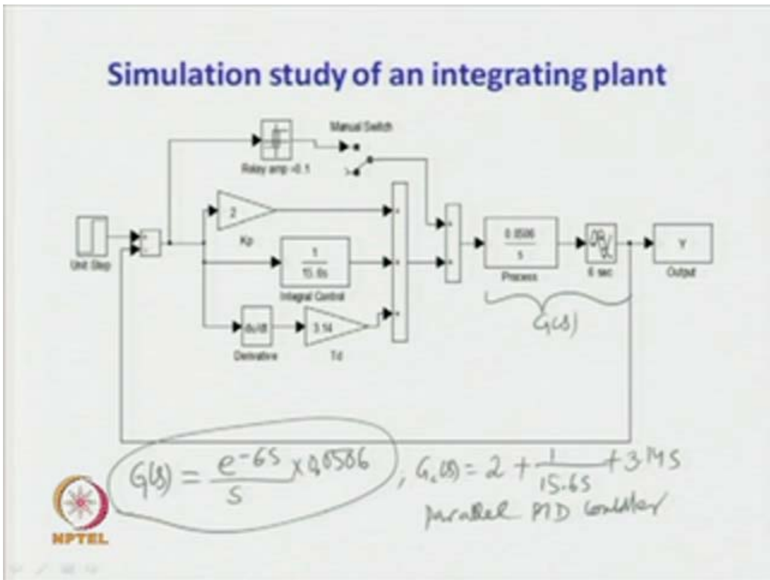

Next, we shall study the online identification of an integrating plant, where the integrating plant dynamics is assumed to be G s is equal to e to the power minus 6s upon s times 0.0506. So, the integrating fast order plus delay integrating process has got a dynamics with constant 0.0506, time delay of 6 seconds and then integrator at the origin. So, this is the process we have G s, now the controller dynamics is written as G c h G c s is equal to 2 plus 1 upon 15.6s plus 3.14s, so again we have got a parallel PID controller in the feed forward path.

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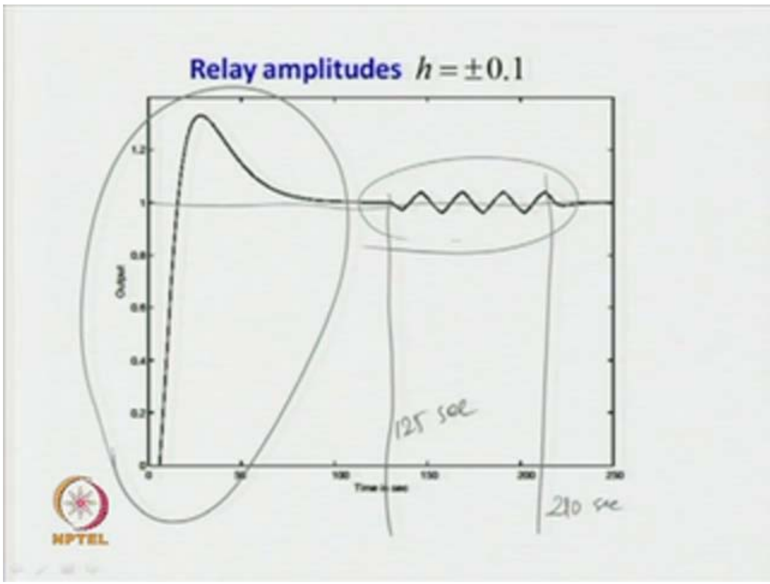

When the relay is switched on at about 125seconds, so when the relay is switched on at about 125 seconds, then limit cycle oscillation at the output takes place, so output becomes oscillatory. And when the relay is switched off at about 210 seconds, so when it is switched off at about two hundreds 210 seconds, then we go back to the steady state response.

Again, if I draw a line, oriental line connecting this, then we see that we obtain symmetrical limit cycle output for the fast order plus dead time integrating process. So, the PID gives poor time domain performances, no doubt. If we look at the transient and steady state responses of the integrating process, for the controller, we are getting a poor time domain performance, for that reason, we need to invoke relay and reset the parameters of the controller to improve the closed loop performance or performances of the integrating plant.

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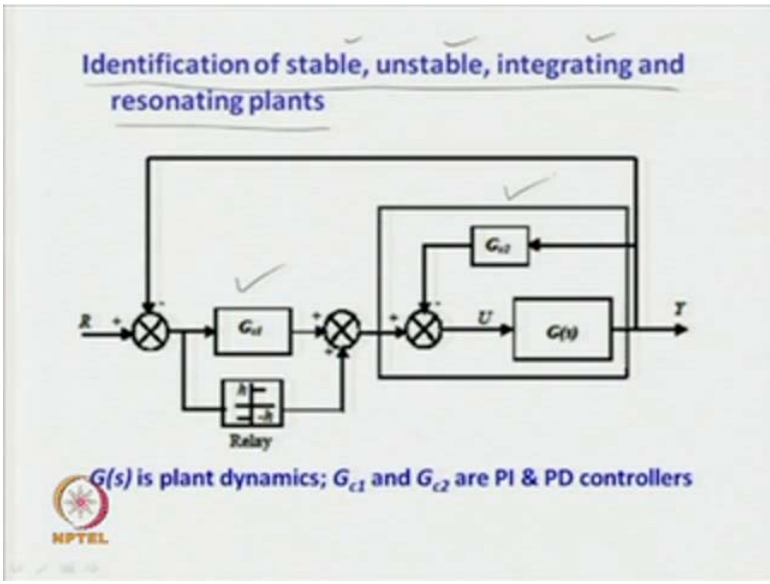

Next, we shall go to another scheme, the third scheme, online identification scheme, which is capable of controlling or tuning the parameters successfully for stable, unstable integrating and resonating plant. So, for a variety of, for a class of plant dynamics, this identification and control scheme can perform well, so what is there in this new online identification and control scheme? We got two controllers, we have got a controller G c1 here and we have got an inner feedback controller G c2.

So, there are two controllers in this scheme, the controllers are given as G c1 and G c2, often which are in the form of PI and PD controllers and G s is the plant or process to be controlled. The relay is connected in parallel with the controller G c1 s, so we have got two controllers in the loop, where as the relay is connected in parallel with the feed forward controller G c1 s. And online tuning scheme using PI PD controllers is found to be quite useful in controlling and identifying the dynamics of plants and controlling stable, unstable integrating and resonating plants.

What is the contribution made by this controller? G c2 can be designed primarily for stabilization of open loop unstable processes, integrating processes and resonating processes. So, the primary job of G c2 is to stabilize the original process dynamics, once we have got some stabilized process, G dash s, I call this as the stabilized process or plant.

So, a controller can be designed for the stabilized process or plant using the relay based auto tuning scheme, so that is what we we our aim is, we shall see the equivalent of this one. If you we make the equivalent diagram of this one, it will it will be apparent the, it will be apparent, the benefits we get from this scheme. So, the equivalent diagram of this one can be made in the form of, we will have the reference input, then we will have the symmetrical relay.

And now, the plant G s, and it will have the controllers PI plus PD or I can write this as G c1 plus G c2 in the loop, so this is what we will get when we draw the equivalent diagram of this scheme. So, the equivalent diagram of this scheme shows us that the relay experiences at plant dynamics which is subjected to inner feedback controllers, where we have both controller present in the inner loop. So, from here, we can make out that in spite of the presence of static load disturbance or external disturbances, the relay will successfully be able to generate limit cycle output and from there, using the measurements, we can tune the parameters of both the controllers G c1 s and G c2 s, this is what we get from this new identification and control scheme.

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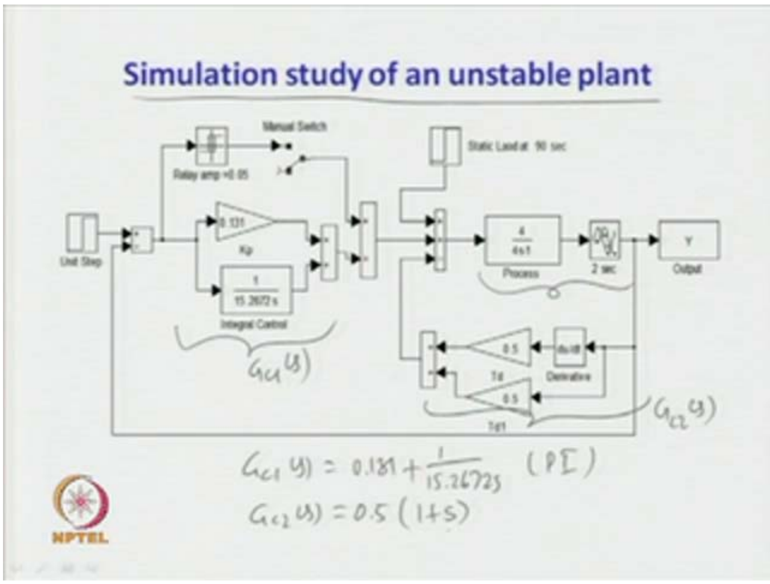

Let us go to the simulation study using the new identification and control scheme. So, in the simulation study of unstable plant, let us consider the same unstable plant we had considered in the earlier case. So, the plant dynamics G s is now 4 e to the power minus 2s upon 4s minus 1, so this is our plant G s, now we have got two controllers in the loop, the controllers are given as G c1 s is equal to 0.131 plus1 upon 15.2672s. So, this is the PI controller we have in the feed forward path, so this is the controller G c1 s, where this is the G c2 s, the second controller is present here, this is the G c2 s. So, G c2 s is nothing but a PD controller, which can be given as 0.51 plus s, so this is the PD controller we have, are the online identification and control scheme. So, when the unstable plant is subjected to the PI PD controllers, then we get a satisfactory time response of the system when the input is unit step reference input.

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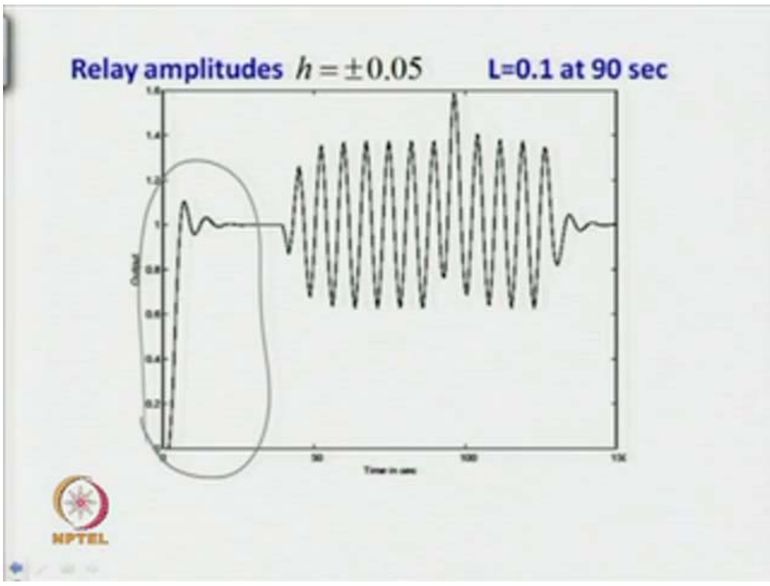

Now, with the relay amplitude of h equal to plus minus 0.05, even in the presence of static load disturbance of magnitude L equal to 0.1, at time t equal to 90 seconds, we get a limit cycle output of this form. Please concentrate on this limit cycle output form, at time t equal to 90 seconds, about this time, the static load disturbance of magnitude 0.1 occurs. In spite of the external static load disturbances as we see from the output, that we get symmetrical limit cycle output and the disturbance is rejected, the effect of disturbance is successfully overcome by the identification scheme and three cycles, three cycles of or cycles of stable outputs can be obtained. So, the beauty of this scheme is that even in the presence of static load disturbances, it is possible to obtain symmetrical limit cycle output, stable limit cycle output from the online identification scheme.

Now, the relay parameter h can be or the relay amplitudes h can be selected judiciously, it is primarily based on the magnitude of output, how much excertion around the steady state value can be tolerated, based on that only the limit cycle height or amplitudes are decided. So, it has become a bit higher as we look at the output signal, the excertion across, around the steady state value is very high. Just for the sake of illustration we have given, chosen the relay amplitudes of high value, otherwise one can choose a small value and get the limit cycle output of desired magnitudes or of desired heights.

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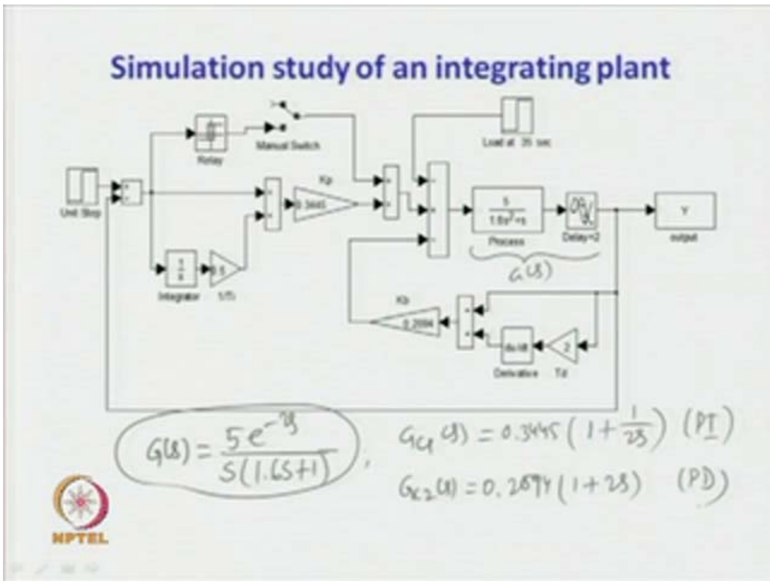

Now, let us go to the simulation study of another plant, this time we have got an integrating plant, the same integrating plant G s, which is given as 5e to the power minus 2s upon s times 1.6s plus 1. So, we have got a second order integrating plant with dead time of 2 seconds and time constant of 1.6 seconds. For this integrating process, for this integrating process G s we have got the controllers G c1 s as 0.3445 times 1 plus 1 upon 2s, so we have got a PI controller in the forward path and we have got G c2 as the inner feedback controller as 0.20941 plus 2s. So, we have got a PD controller in the feedback path, with this PI PD controller it is possible to get satisfactory time response from the closed loop system.

Now, as far as auto tuning is concerned, the relay is switched on and then we get limit cycle output signal. So, when the relay is switched on, even in the presence of a static load disturbance which occurs at time t equal to 35 second, we get relay output signal of this form, say, if we carefully observe, when the relay is withdrawn, then also we are going back to the steady state condition.

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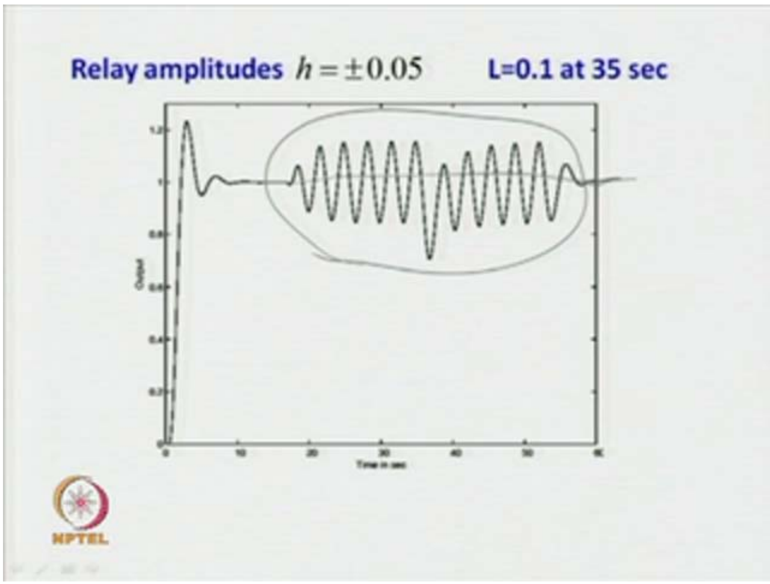

Therefore, the effects of static load disturbances are successfully rejected, so the limit cycle output is not affected by the static load disturbances. So, when the relay setting is of magnitude or amplitude h equal to plus minus 0.05, then we get a limit cycle output of this form. When the static load disturbance of magnitude 0.1 occurs at time t equal to 35 second, t equal to thirty five second, then then the initially the transient effect of the relay output signal is over here, then we go back to the steady state condition of the limit cycle output.

So, measurement should be made only on the steady state part of the limit cycle output, therefore please allow three cycles of limit cycles, stable limit cycle output before switching off the relay test or before switching off the relay from the scheme. So, this is what we get from the simulation study of an integrating plant. Next, so far what we have done, we have considered the effects of static load disturbances and we have seen that the static load effects of static load disturbances can be successfully rejected with the use of the advanced online identification and tuning scheme.

How this is different from the earlier scheme? Only we have got the feed forward controllers splitted into two parts and we have put part of that in the feed forward path and part of the controller is put in the feedback path. The primary objective of putting a controller in the feedback path has always been explained in our earlier lecture, basically the open loop unstable process dynamics can be manipulated, so it is possible to place the poles of the open loop unstable process at some desired location after that is done, then the parameters of the controllers can easily be set using the relay auto tuning tests.

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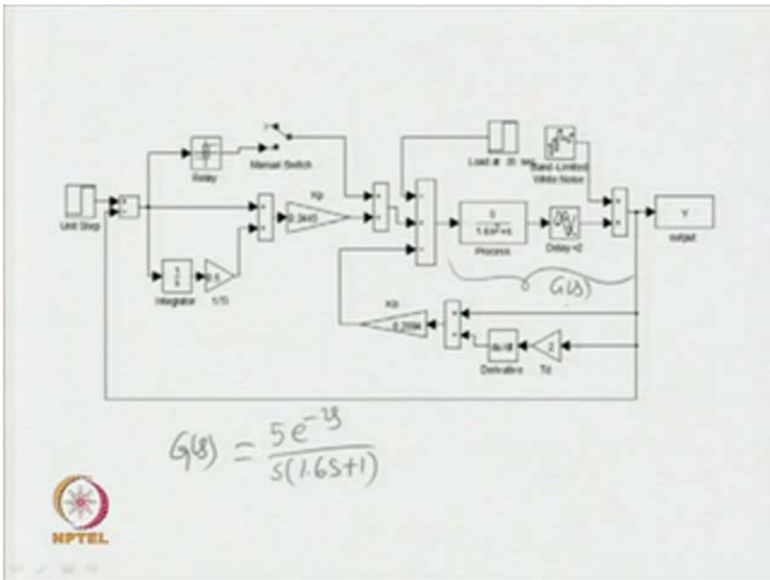

Next, we shall see another simulation diagram, with the same simulation diagram we have used for considering the control of identification and control of second order plus dead time integrating process. The integrating process dynamics G s is known to us, that is 5e to the power minus 2s upon s times 1.6s plus 1. So, this is the G s we have got and the same controllers are used here apart from the band limited white noise. If you look at carefully, this simulation diagram includes another block and this block is put here to consider some realistic case, sensors are responsible for introducing measurement noise or noise in closed loop systems.

To simulate the effects of sensor noise, we have included a block named as band limited white noise, so the sensor is assumed to have band limited white white noise of power 10 to the power minus 4. So, the noise power is 10 to the power minus 4, so when some units take reference input is applied in the presence of static load disturbance of magnitude, L equal to the same magnitude we had 0.1, so L equal to 0.1 at time t equal to 35, we get an output response of this form.

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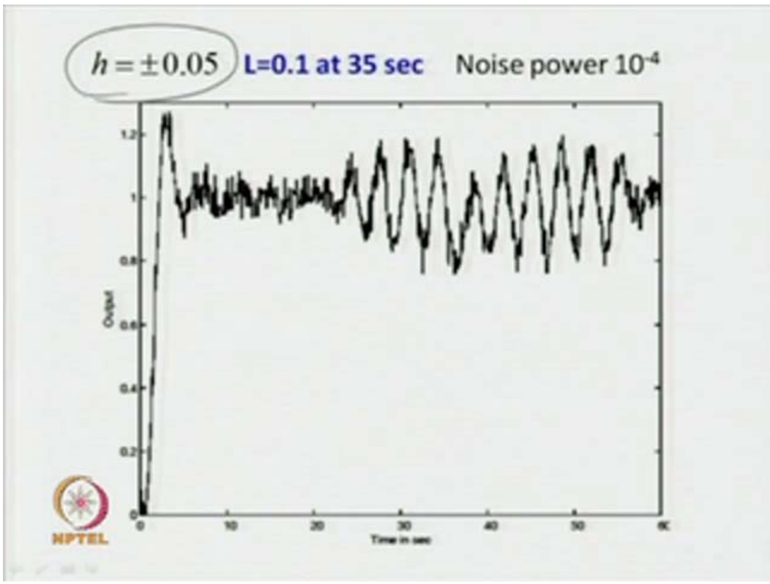

So, the relay amplitude is set at plus minus 0.05, a static load disturbance occurs at 35 seconds, the magnitude of the static load disturbance is 0.1, sensor noise is present from the beginning, so we have got bend limited white noise of power ten to the power minus 4 available from the beginning. So, the output signal assumes this form, when we have got sensor noise, static load disturbance and relay heights presents or relay amplitudes present, we get the output of this form. This output signal is a bit realistic output signal of a control system, real time control system, which is subjected to reference input, static load disturbance and sensor noise input. All sorts of inputs are present, how can we make measurement? Now, this output, the relay system, relay control system output or limit cycle outputs signal can be analyzed using web lag transform or some tool boxes using various techniques.

So, use of all those techniques can enable us to retrieve back the original output signal, limit cycle output signal, which is of the form shown over here. So, this is actually the output signal we have got, the original output signal in the absence of noise. So, when there is no noise, we should get this type of output signal and when we consider the stable three periods of the output signal and then the output signal should be of this form.

So, when denoising technique, noise reduction technique is made use of at that time, these part of the signal or this part of the signal will give us denoised output signal from where easily we can make measurements and then subsequently we can set the or update the parameters of PI PD controller. So, this is what we get from the online identification and tuning scheme.

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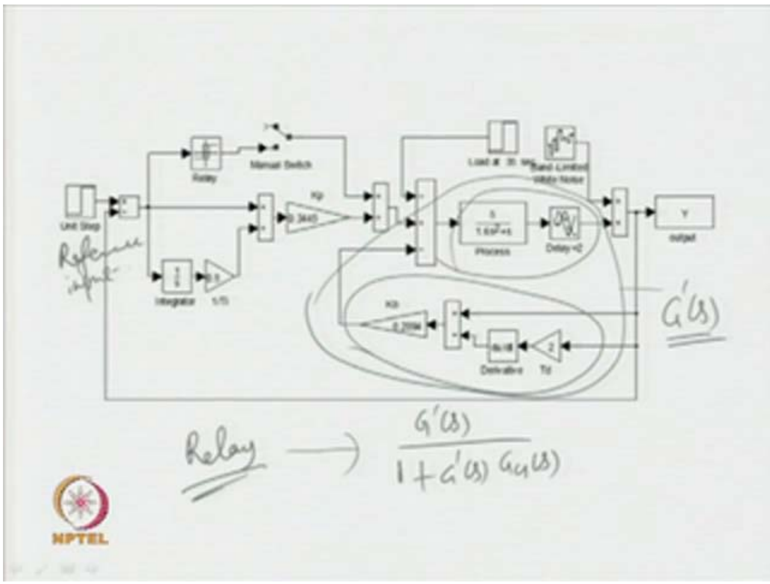

So, let us clearly look look back at this simulation diagram, what are the things we have got now. So, we have got the process which is subjected to one inner feedback controller, a PD controller, there by giving us or a stabilized process, so this part can give us the dynamics of a stabilized process. So, G s becomes G dash s, where G dash s can be written as G s upon 1 plus G s times G c2 s, so this is how we get the dynamics of this one. When the relay is present or is is in action and when the block diagram is reduced, then the relay ultimately sees a typical transfer function which can be given in the form of now G dash s upon 1 plus G dash s G c1 s.

So, this is what is seen by the relay, so the relay sees a modified process of the transfer function form of given by G dash s upon 1 plus G dash s G c1 s. So, when I substitute back the transfer functions of G s, G c1 s and G c2 s, then we get a closed loop transfer function, which is subjected to the relay test, from that analysis it is possible to visualize the type of symmetrical output we can expect from the scheme. Now, this relay, how to set the relay parameter that is one important question that we shall discuss after some time.

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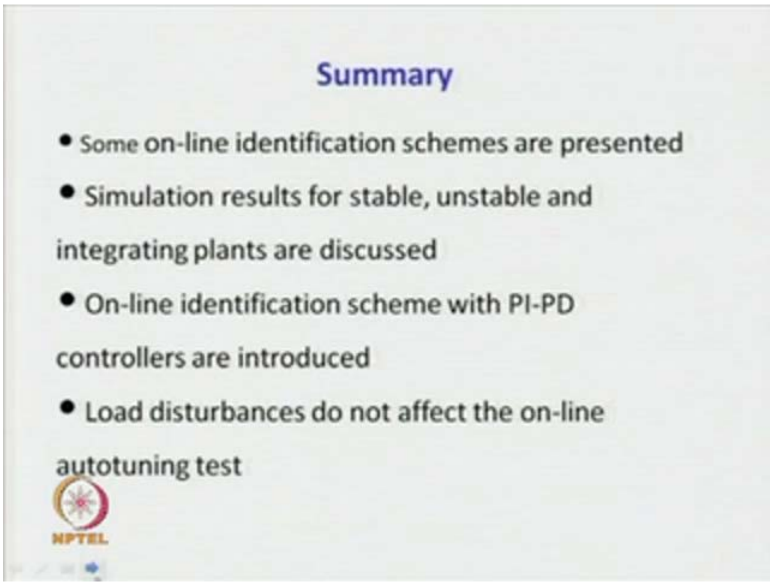

Let us go to the summary of the lecture. So, three types of online identification and control schemes have been discussed, we have found that the online identification and control schemes are better than the offline identification and control scheme as far as static load disturbances and asymmetricity of limit cycle output signals are concerned.

Simulation results for stable, unstable and integrating plants are discussed and the simulation result show that the effects of static load disturbances can be countered easily using the advanced identification and control schemes. Now, the last identification scheme we discussed was an identification scheme, where there were two controllers present in the identification scheme. The contribution of individual controllers were discussed individually and the the beauty of the online identification scheme as far as noise input, reference input and static load disturbance inputs are concerned, were discussed. What do we have found from the discussion that load disturbances do not affect the online auto tuning test, whereas sensor noise gives us distorted limit cycle output and to counter the effects of sensor noise, one may has to refer to some other technique.

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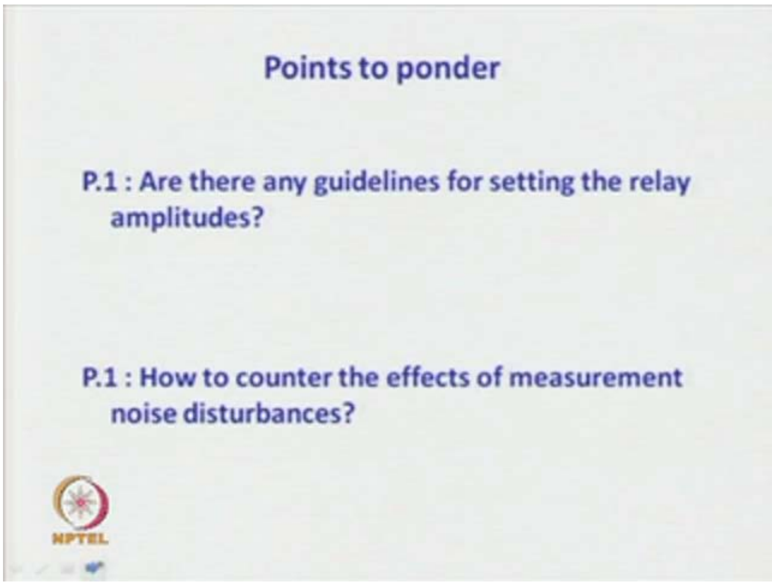

Some points to ponder. First point can be like this, are there any guidelines for setting the relay amplitudes? Generally relay amplitudes are decided based on the signal to noise ratio of the limit cycle output signal. When the limit cycle output is very much noisy, in that case, one has to judiciously choose the relay amplitudes. Minimum three cycles of stable limit cycle output must be obtained for making or before making measurements on the limit cycle output.

The second point is how to counter the effects of measurement noise disturbances. So, the measurement noise filters may be employed as we have done earlier in one closed loop control scheme to counter the effects of measurement noise. So, measurement noise can be successfully eliminated, provided we have got noise filters in the loop. When the noise filters are not used for ease in operation of many system or ease in analysis of many systems, in that case, some data reconstruction mechanism are to be used or some denoising technique like wavelet based denoising techniques or fourier transformed based, FFT based corfeiting techniques may be used; that is all in this lecture, thank you.