Digital Control in Switched Mode Power Converters and FPGA-based Prototyping
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Module - 01
Introduction to Digital Control in SMPCs
Lecture - 02
Digital Control of SMPCs - Course Instructions, Guidelines and Resources

Welcome back in this lecture we are going to talk about this as a continuation of the first lecture and here we want to talk about the Course Instruction, Guidelines, and Resources for the course Digital Control of Switch Mode Power Converters.

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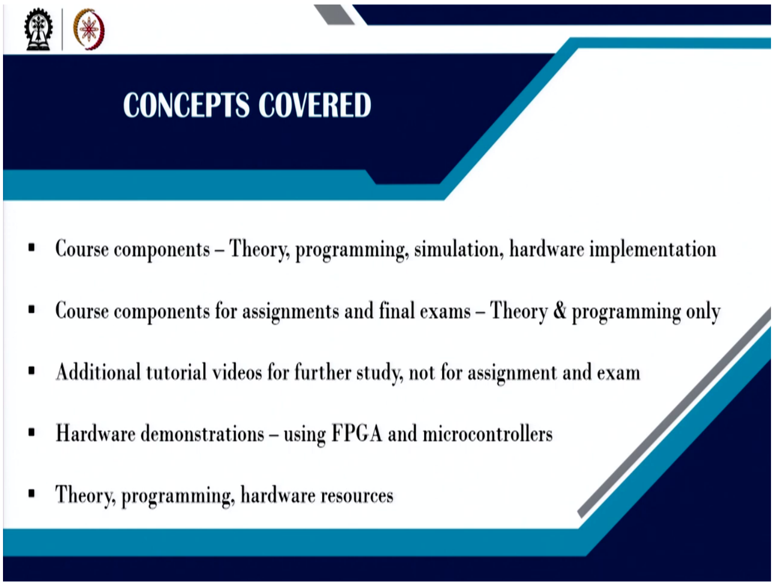

So, in this lecture, I will first talk about what are the course components in this course? So, in this course we will have a theory, we will have programming, we will have simulation, and hardware implementation. Then we will also talk about which part of this course will be included in the assignment and final exam.

For example, we will include theory and programming only, but hardware implementation is optional I mean it is not part of the assignment or exam. Then the additional tutorial video will be given or provided in this course which again is not for exam or assignment, but is for further study, and hardware demonstration will be made using FPGA and microcontroller as well as theory programming and hardware resources.

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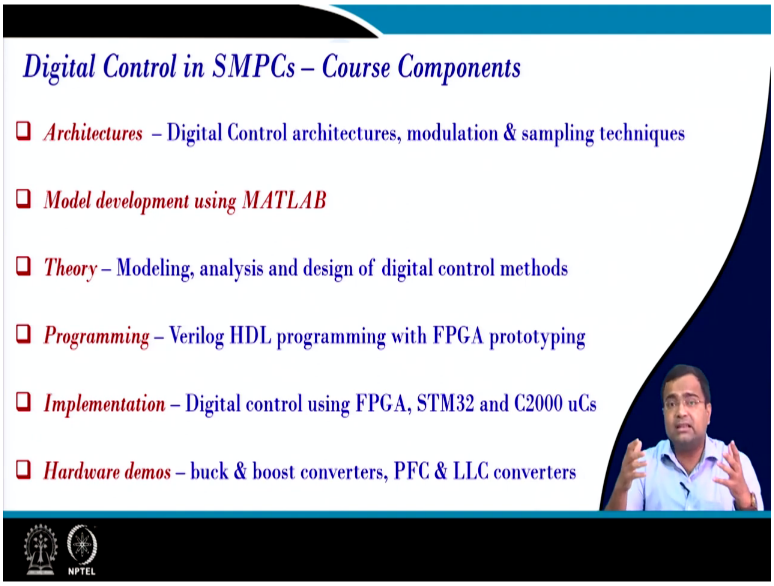

So, the first thing Digital Control in Switch Mode Power Converter is the course component. So, in this course, we will have an architecture part that will include digital control architecture like a current mode control, voltage mode control architecture, and digital architecture then we will have constant on-time digital current mode control constant, off-time digital current mode control, peak current mode, fixed frequency digital control and so on.

So, there is various also digital pulse width modulation architecture. So, various architectures will be presented. We will talk about different modulations, trailing edge modulation, leading-edge modulation, and what is the sampling technique under trailing edge modulation, what is the sampling technique under leading edge modulation, then how to sample under constant on time, and how to sample under constant off time.

How to sample under hysteresis control? So, all this will be discussed. Then we will talk about model development using MATLAB. So, we will develop MATLAB custom Simulink as well as dot m file; that means, a custom interactive model development for this digitally controlled converter. Then in the theory, we will talk about modeling techniques. How to derive a model there are different types of models, like a continuous time model, we will say whether the continuous time model can be used or extended for digital control or if they are not sufficient.

Then whether we need a more advanced model like a discrete-time model and we will talk extensively about the discrete-time model. Then we will show how this modeling technique how far they can capture. For example, in our previous course on the control and tuning method that course we learned that this modeling technique is like a small signal modeling technique. If we get the linear transfer function model and obtain the step response AC couple response and if we add the DC component then we have compared with the actual switch simulation.

And we saw that model reasonably captures the behavior up to 1 by 10 th of the switching frequency and beyond that actually, the model starts diverging. But in this course, we will show such a model may not be even sufficient for digital control even under low bandwidth also. So, we need to go for fully like a discrete-time model.

But such a discrete-time model may not be in terms of you know intuitive like in terms of the pole-zero concept and you know how they are mapped into power stage parameters which we can very easily visualize in a continuous time model. So, here such a discrete-time model will have a lot of mathematical formulas, matrix exponential so that you cannot visualize such pole-zero or impedance effect, but it is very accurate.

So, how to balance how to design the controller using the conceptual pole-zero concept and how to slowly move into the discrete-time we will also discuss. So that means, we want to utilize both our concept as well as accuracy. So, we can design as well as validate, so that is the objective. Then we want to discuss programming, we want to learn there are two types of hardware descriptive language Verilog and VHDL which are often used, but in this course, we will talk about Verilog HDL programming.

And we will develop from scratch; that means, you know from the basic digital circuit and then how such digital circuit can be extended to actually implement a full-scale digital control. For example, for the digital pulse width modulator, for example, we want to implement a digital PID controller and I will also show what is the top-down design method. So, if you want to implement an overall PID controller how it can be broken down into pieces and actually implement different modules and then create a main module to integrate this?

So, this kind of flexibility will be discussed in detail. Then we will also talk about fixed point implementation and what are the steps for FPGA prototyping. Then in this implementation process, we will implement digital control extensively using FPGA and we will use Xilinx

FPGA, but you can also use this Verilog code and you can use Altera or other FPGA devices. But apart from this, we will also present some demonstrations using STM 32 as well as the C2000 series microcontroller ok.

So, this microcontroller will be also discussed briefly on how to program it, and then using that microcontroller some case studies of power converters will be demonstrated by the expert of this ST microelectronics as well as Texas instrument. Then hardware demonstration will be shown using buck and boost converters as well as for using FPGA devices extensively, as well as some case studies of power factor correctors and LLC converters will be also shown using microcontrollers.

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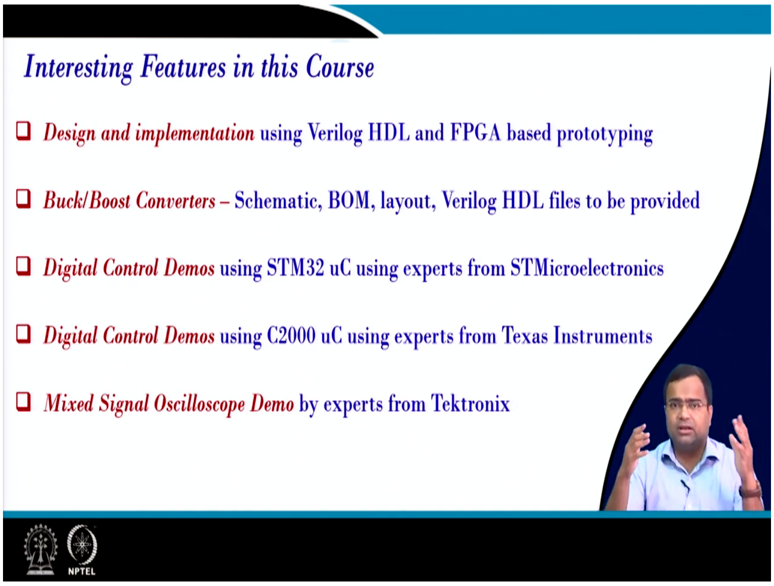

What are the interesting features of this course? So, this course is somewhat unique in the sense that this course will have the design and implementation where whatever we learn in the theory we want to implement in the hardware and there will be some additional tutorial video where we want to see if you get a transient response using your design model a MATLAB model and you want to get the response. And then if you implement the same controller using an FPGA in a hardware's actual hardware.

We want to show the response how they are different, whether they are different or they are the same, and because all practical things may not be captured and if they are not exactly identical how far they are different and what is the cause of such difference we will try to study some aspect. But this will be mostly for demonstration purposes and may not be part of the exam. So, we will show Verilog HDL base FPGA prototyping and step for implementation.

And we will be using Buck and Boost converter which I have shown in this lecture. Also, I will show the picture of the test setup and we will provide the schematic of our test kit. That means, Buck and Boost for the power stage and we will also provide the schematic and also layout file for the signal conditioning board we are using an off-the-shelf or commercial know FPGA kit you know Xilinx FPGA. So, that also part number will provide.

So, that you know if somebody interested is interested to actually validate you can do it, but we will provide the information. But again this hardware implementation is not part of the assessment in the exam ok. So, this file will be provided along with our Verilog HDL programming file. Then I will also show a lot of digital control demonstration, sorry using FPGA based demonstration anyway we will be showing extensively in this course.

But apart from that as I said few design case studies let us say using the PFC converter case study here using STM 32 microcontroller the LLC converter controller case study will be shown. Similarly, we will show a digital control case study using for PFC converter using a C2000 series microcontroller and a Texas instrument design expert will be demonstrated. In this course, we will be also showing how to use mixed signal oscilloscope because we are also dealing with digital control.

So, naturally our power converter all signals are analog like you know if you try to see the output voltage inductor current waveform, and gate signal we use the analog probe for the oscilloscope right to show. But at the same time, we want to also see some of the digital control signal digital signal rights. So, we need or want to test some of the let us say digital comment signals. So, how to use it? That means, we need a mixed signal oscilloscope in which there will be a dedicated analog channel as well as a digital channel.

And here you will you can see the digital current waveform or digital signal waveform in the analog channel, but there is a penalty. That means, it will unnecessarily slow down you know some of the rising or the sharp edges, because in the analog probe basically use you have to maintain linearity, as a result, it has a bandwidth limit.

But there are dedicated digital channels are there in the oscilloscope which are used to actually precisely show the digital control waveform. And such demonstration of how to use mixed signal oscilloscope what are the different functions that will be demonstrated by an expert from Tektronix.

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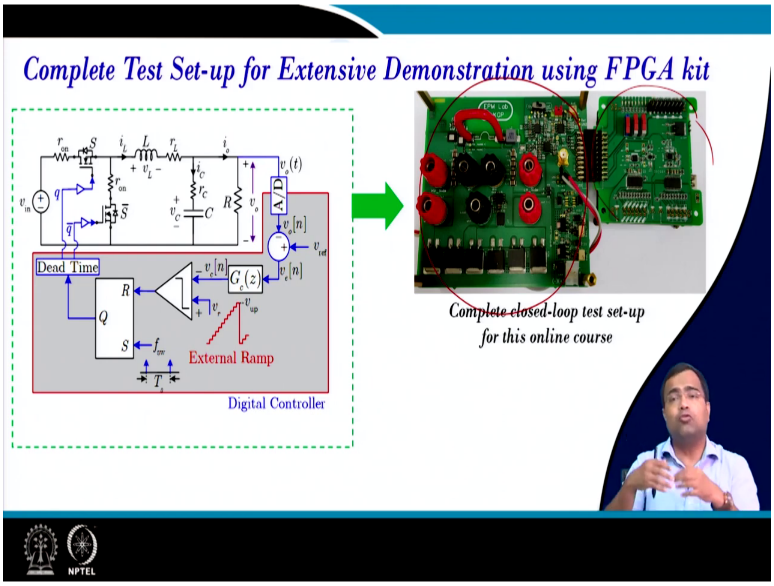

Then this is a complete test setup where we have these signal conditioning boards and below the signal conditioning board is a board-to-board connector is there, and we have an FPGA kit that is there. And this is the power stage board, so from the power stage board, you will measure the sense voltage as well as the current sensor.

And those will be passed through the signal conditioning side and the signal conditioning side will have a to d, d to a converter as well as you know buffer circuit and other signal impedance matching network, and then finally it will go to the FPGA.

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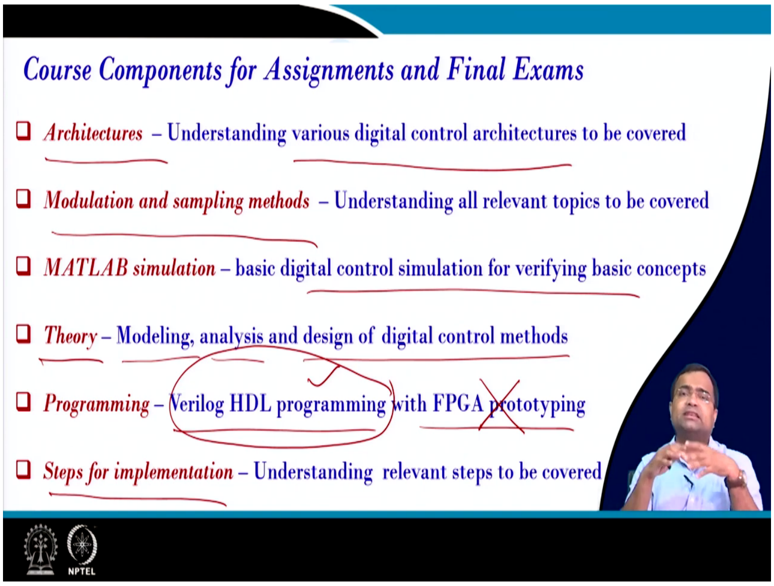

Now, the course component for assessing assignments and the final exam. So, it should be you know we should keep in mind in this course there will be a lot of demonstrations which will be covered.

But for the exam as well as for the assignment only the limited part which is the architecture will be covered completely as a part of the assignment and the exam. Where there will be various digital control architectures that will be covered in the class the theoretical part, architecture, and circuit diagram should be part of the assessment assignment as well as the exam. Similarly different modulation and sampling methods will be part of the assessment for the exam as well as the assignment.

MATLAB simulation although we are not going to you know for the exam we are not going to ask students to simulate live. But we may ask the student in the assignment that if they simulate a model which will be showing how to develop the model, then we will be asking what is the steady state value whether this gain you are getting stability issue. So, this is for cross-checking because this will help you that you should do MATLAB you know the process will be shown extensively, but you should actually develop your own MATLAB file and run it.

Then only you can visualize the digital control otherwise the learning will be incomplete. So, in the exam and the assigned assessment sorry for the assignment purpose only, this will be only used in the assignment. Where we may ask that if you simulate a let us say a digital voltage mode control buck converter and everything will be given in terms of the power stage, will provide you fix switching frequency everything will be provided then you have to check what will be the steady-state waveform.

What is the average inductor current and so on? What is the ripple parameters ok of course the theory is very much in the part of the exam as well as the assignment, where we will be talking about a lot of modeling technique. How to analyze? You may have to find some results of stability then we all ask for some design case study; that means, how to design a compensator digitally and we will be covering this thing in detail. So, this will be part of the exam.

Also, we will be covering a lot of in-depth Verilog HDL programming and FPGA prototyping, but only Verilog programming will be part of the exam and assessment.

So, FPGA prototyping will not be asked we are not going to ask you that you prototyping using FPGA because we will show if you can have a Xilinx you know even the verification of this code in simulation that we are not going to ask, but whether you are able to write a Verilog HDL code or not that may be part of the assignment or that may be some part of the exam, because we may ask some objective type question using this Verilog HDL coding.

So that means, Verilog HDL programming will be taught in detail and some parts will be actually part of the assignment and exam. Finally, we will provide steps on how to implement for example, if you want to implement using FPGA or even there will be some demonstration using a C2000 series microcontroller or STM 32 microcontroller. We may ask what are the steps?

Because that lecture will be part of the course. So, you may not be asked to actually implement that using either this microcontroller FPGA, but you should know what are the summarized step for implementation. So, that step if you understand thoroughly you prepare yourself may be helpful in the future. So, that future you know not beyond this course you want to implement you go to industry or particularly this is useful for the industry practitioner they may try to in their design. So, that is why these steps are important.

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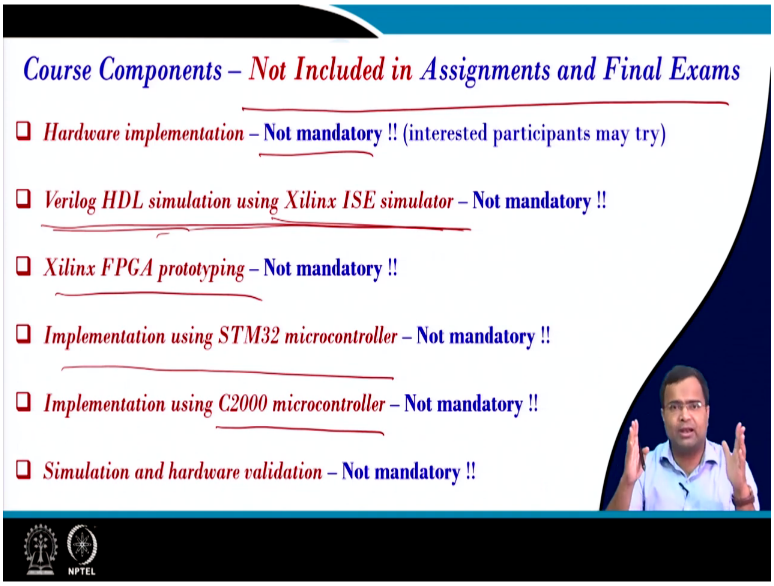

Then in this course what is not included in the assignment and exam? It is there in the course material as well as the lecture. But it will not be part of the assignment and the exam will be hardware implementation, which means it is not mandatory. That means, you do not need to implement hardware you do not need to buy any power stage anything you can just refer to this course and you only need to do some sort of MATLAB.

So, hardware implementation is not mandatory, but if there are some interested students who want to actually implement we will provide you with all the detailed documentation ok. So, you may try it out but this is optional. Similarly, Verilog HDL simulation how to use ISE simulator using Xilinx is not mandatory; that means, you may not need to actually implement Xilinx ISE simulator; that means, you may not need to install ISE simulation software.

Because sometimes you know it may not support different types of you know because whatever we will be using if it does not support your computer. So, we are not including this simulation or you do not need to install the Xilinx ISE software for part of the assignment and the final exam. But you need to know how the effective way how to implement Verilog code ok. But we may provide you with some open-source you know a software that can be used to check your HDL coding.

It is not mandatory that you have to use Xilinx ISE for checking because there are many other open-source tools available where you can check your HDL coding. So, ultimately you have to learn the Verilog HDL programming part of this course, but for simulation using ISE is not mandatory, similarly, FPGA prototyping is not mandatory as I have already mentioned. So, you do not need to buy any hardware parts just to get a certificate for this course.

But any interested student can do that and implement it, then implementation using STM 32 microcontroller that will be demonstrated. But again it is not mandatory you do not need to buy any software you do not need to buy any STM 32 microcontroller for getting this course certificate as well as you do not need to buy a C2000 series microcontroller. So, these are part of the demonstration for learning, but you need to know the step for implementation.

And finally, for simulation and hardware validation we will be showing how to validate using MATLAB your design; that means, your analytical model the result obtained from the discrete-time model as well as your MATLAB simulation we will show you validation. But that is not part of the assignment and the exam, you do not need to validate and that will be not asked in the assignment. But hardware validation you may try it out that is also this part it is not part of this course.

So, this will be shown just to get an idea that what will be deviation can you really validate. So, only learning this process will be covered in this course.

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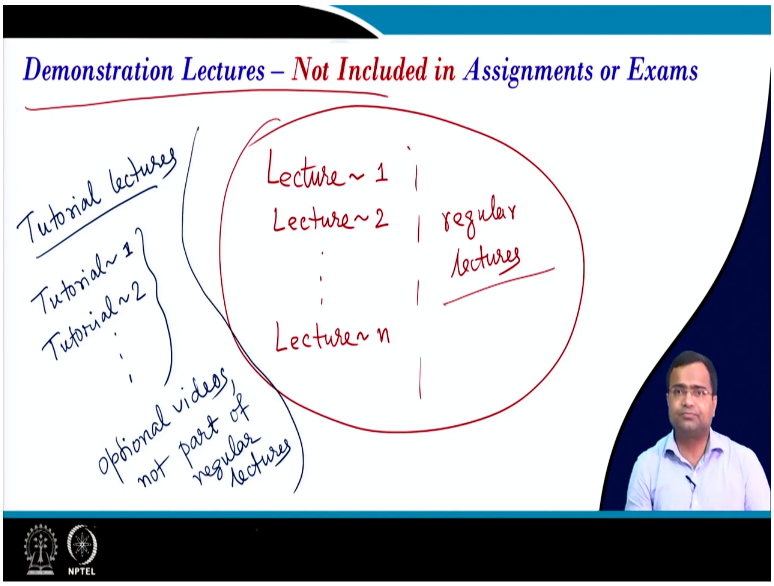

So, in this course, we will be showing a lot of demonstrations and in this course apart from the regular lectures, there will be some additional lectures and which we call tutorial lectures.

That means, one will be a lecture; that means, whenever you will find lecture 1 lecture 2. So, this is like dot dot dot there will be multiple lectures n.

Whatever so, this will be part of these are the regular lecture and we have already discussed it in the regular lecture which will be covered in the assignment and the exam. But apart from this regular lecture apart from this, we will also have some tutorial lectures which will be numbered as tutorial 1 and tutorial 2 like that dot dot dot. But these are not part of this optional video. So, these are optional videos and they will not be part of not part of regular lectures.

So, these are the optional video tutorial lecture that will be also covered in this course; that means, this will be you know maybe 1 week you may have some 2, 3 this tutorial lecture tutorial 1 tutorial 2 like this. But again those who are interested can go through this video, but for the regular class assessment, these videos will not be considered ok.

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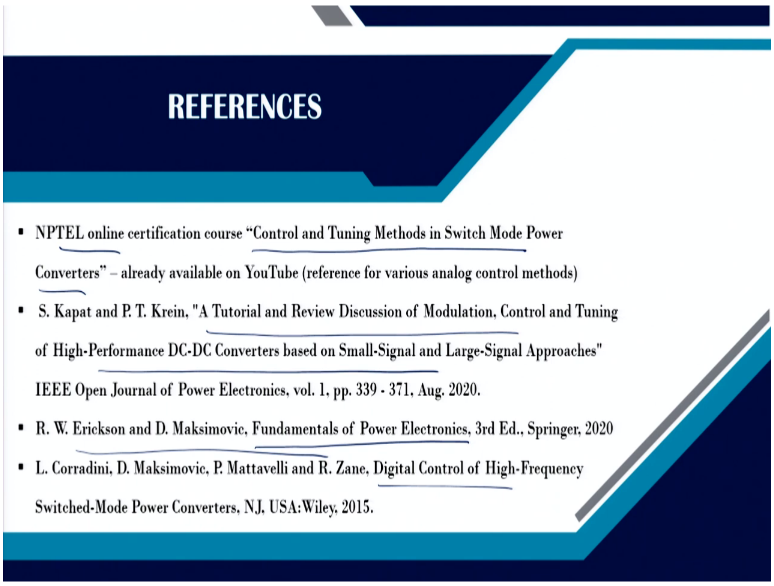

So, in this course, I just want to summarize what are the reference material that will be used. One is our earlier course NPTEL course the control and tuning method in switch mode power converter. So, this is already available on YouTube and in this course because this particular course is actually this course has discussed in detail different analog modulation control techniques for analog control. So, whenever we will start our digital control we will refer to some basic analog control as a starting point.

And we will take it for granted that those basic analog controls are more or less known, but we will provide you the reference link. So, that one can go into some of this lecture of this course and get detail. So, this is one tutorial paper where one can get a summary of different modulation and control techniques, but this is for analog control. So, for digital control some basic this book is fundamental of power electronics, you know in this book actually later part of this book covers some starting of digital control.

So, one can get some basic idea of digital control here, and this book on digital control of high-frequency switch mode power converters may be useful for some advanced topics. But in this course, I will primarily highlight the majority of these topics you know in this course material. So, you know even if one does not go through all this material, we will refer to a particular lecture about what concept we will be talking about, and there direct you know all the diagrams that will be provided.

That should be more or less enough for this course assessment and understanding. But for anything detailed about the research topic we will provide some research paper links as well as anything related to you know some architecture and exploration of other converter topologies. So, you can give me provide with some reference links. But this course material whatever will be covered should be self-sufficient for this course. So, with this, I want to finish it here.

Thank you very much.