Digital Control in Switched Mode Power Converters and FPGA-based Prototyping
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Module - 01
Introduction to Digital Control in UMPCs
Lecture - 03
Examples of Some Commercial Digital Control Solutions

Welcome, so in this lecture, we are going to show some examples of Commercial Digital Control Solutions.

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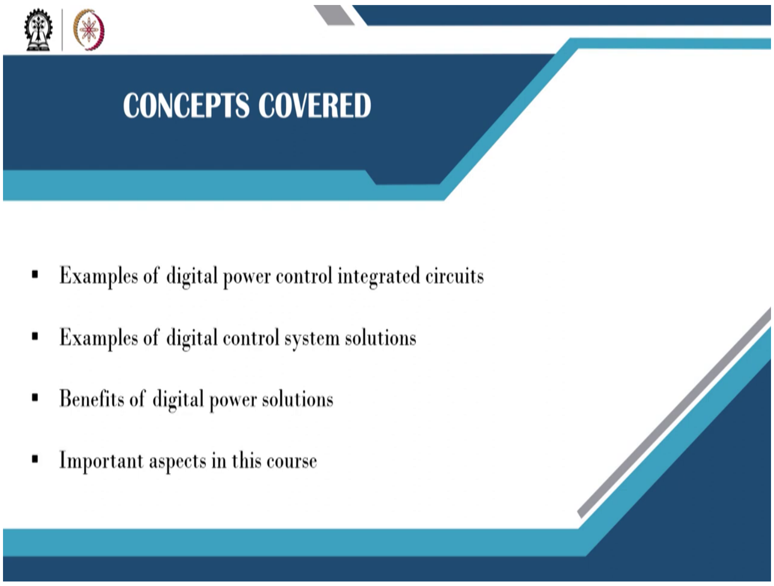

So, I will first talk about some examples of digital power control integrated circuit IC. Then I will show examples of some digital control system solutions like you know system-level solutions. Then what is the benefit of digital control I will also explain some benefits which are mentioned with those examples product datasheet and then I will show what is the important aspect of this course?

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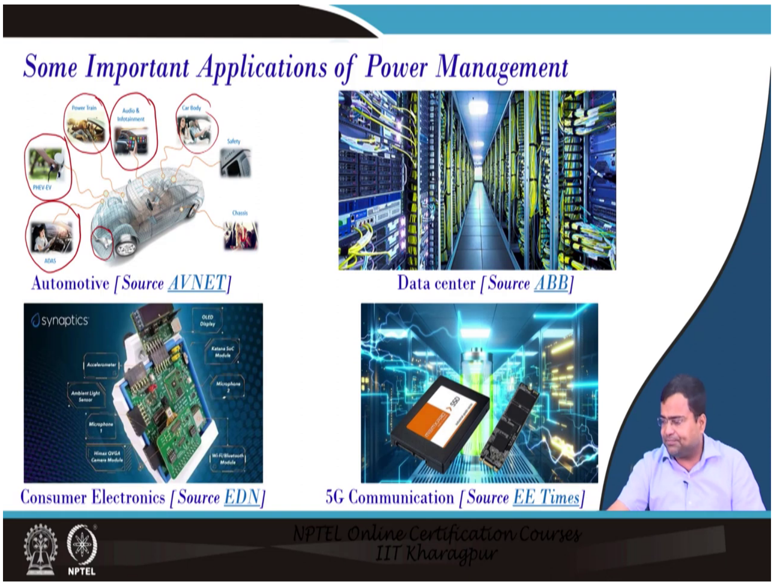

So, some important application of Power Management if we talk about power management one of the very important applications is automotive. And if you take automotive-like you know in the car it need not be always electric vehicle; that means, every car if you go inside you know the automotive. That means, the body electronics infotainment system, ADAS is independent of whether it is an electric vehicle or hybrid vehicle, or even a conventional car.

So, now all cars are going for more electrification; that means, you will have more increasing use of electronic devices. But in addition to that now for EVs is the further electrification of the power train also. So, if it's going for this automotive application; that means, the audio and infotainment system you have increasing use of you know power electronics; that means, power management.

For example, if you go for audio most of the cars are going for a class D audio amplifier, which is a switch mode power converter. Then the infotainment system you need you to know like a dashboard you need like you know apart from audio display devices, you know other computational devices. So, there is a huge amount of electronics and you need power for every electronic device.

Then the power train you know the power train if you go for the electric vehicle the power train is going to be electrified, because you will be using the electric motors and then battery driven you know electric car and it can be hybrid or in a fully electric vehicle. Then we will also have a charger for EVs; that means, you know it can be a board charger or off-board charger and those actually have a high level of power electronics and where digital controls also play a significant role.

Then now there is an increasing need for ADAS for safety and security purposes, the advanced driver assistance system where you know that there will be real-time communication between the satellite and the car. So, as a result, you need high-speed communication as well as high-speed computation, because there will be a lot of signal processing. So, as a result the computational load also increases. So, challenges in power electronics.

So, then body electronics you know all this car also you have a display like in LED driving; that means, the now it is increasing use of LED driving LED load lighting for the car as well as the regular conventional like you know office application, house application, LED TV everywhere the lighting application LED is coming up.

Another example is the Data Center, where you know a data center now everything is like a cloud server; so that means, we are accessing most of the computational facility where the actual computational load is sitting somewhere else in the distance. So, here in the data center even the server you know now we talking about the Google servers standard where 48 volts of direct pol.

So, if you are we are talking about the low voltage high current application, where the voltage level can be 1.8 volts or below the currents can be several hundreds of amperes or it can be even more than a thousand amperes when you are talking about the cloud server.

So, for such applications then there is increasing use of digital control for power management you know controller IC and we will take some case studies some example case study.

Now, we also have increased use of consumer electronics particularly mobile phones. So, a smartphone now becomes like a mini-computer and if you go inside the smartphone you know we are you know making a video conferencing, we are playing games and we are talking. So, everything we are doing through mobile phones. So, a mobile phone has a high dynamical load and you need to meet a very high computational demand as well as you know you also need to ensure the battery life can be extended for a longer duration.

So, all these require you to know the significant challenges of power management, and where digital power management is coming, from so that you can meet this stringent requirement in terms of performance and efficiency. Another requirement is 5G communication. So, if you talk about 5G communication the bandwidth of communication is extremely high and when you communicate then actually your device has also you know to be compatible with the communication speed.

So, as a result, the signal processing required in the computer as well as in the base station of the 5G communication is extremely high, because we are talking about you know that in it is similar to a server application where the current can be hundreds of ampere or thousand amperes with low voltage application. Let us say it can be 3.3 volts 1.8 volts or below.

So, for such applications, the computational load is the current load like a type of load. So, your control requirement becomes significant along with the power converter topology. So, you need to like the digital controls that are coming up you know very aggressively all these applications.

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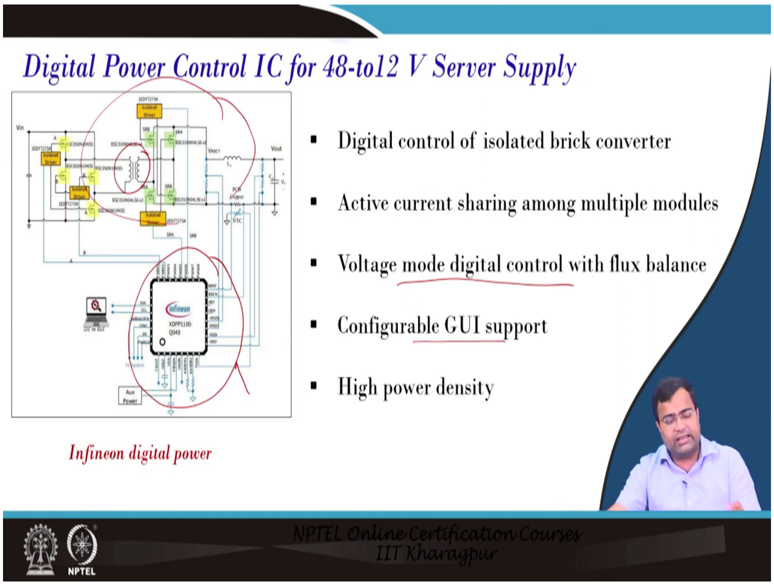

So, I am taking one example like 48 to 12 volts; that means, as I told the server application where the Google server standard talk about 48 volts to POL; that means, the server load.

So, one of the requirements is the 48 volt to 12 volts and then 12 volts on the downstream side it can be a multi-phase converter, or it can be a series capacitor buck converter there are many architectures. So, I am showing one example of 48 volts to 12 volts using an isolated converter, where it is the Infineon digital controller IC which is used to control this isolated converter.

And this IC control is the plug and play that mean digital brick. That means, multiple isolated brick converters can be controlled by this IC, then this IC since we are talking about multiple bricks. That means, 48 to 12 volts if the power requirement is high then one such brick will not be enough, because its power rating can be typically a few hundred watts.

And if you need more and more wattage, so you can put such bricks in parallel. That means, their input and output will be common. But for such parallel bricks, you need to ensure that the current share among the bricks is equal unequal current share can lead to potential damage, so this controller also offers the current sharing.

And also when you are going you know that if the load power level changes dynamically, then you need to shut down some of the bricks also. Then for one of these bricks, the control logic uses a flux balance mechanism because in any isolated converter, you have to be very careful about the control and you have to ensure the flux of the magnetic. That means the transformer should not go to the saturation limit. That means you have to ensure that the flux is properly balanced and we also need to ensure the flux is properly utilized.

So, this flux balancing digital control is they use using flux balance method, but it is a voltage mode control and this IC also offers a GUI graphical user interface support. And this is one example you can get detail from the digital part number of the IC and this also offers very high power density, because all the controller compensator logic everything is inside the IC.

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Another example I am showing is the Renesas digital power solution for the data centers, where we are talking about five g communication, cloud server, where the current level can be hundreds of amperes or thousand amperes with a low voltage application.

Here in this isolation you know you can have a cloud server you know it can be 48 volts to pol application, it can be 2 stage architecture where one stage can be a hybrid switch capacitor followed by multiphase or it can be an LLC converter followed by multiphase. So, there are such various architectures exist.

Now, for this particular IC what is written in the datasheet is that it uses a charge mode control because when you go to digital it is not necessary that whatever analog control we have designed. Let us say for a small signal base design digital will be some z domain of the small signal no.

So, digital control offers you more flexibility to implement non-linear control and this IC uses something like a charge mode control for a very fast transient response. So, you can get charge-based controls to implement near-time optimal recovery near-time optimal control algorithm.

And this IC uses you know a control logic where the current loop is inherently stable although maybe detail may not be available. But in general, if you use a variable frequency digital current mode control I will be demonstrating in this course, you need not require any ramp compensation because it is inherently stable and that we know also.

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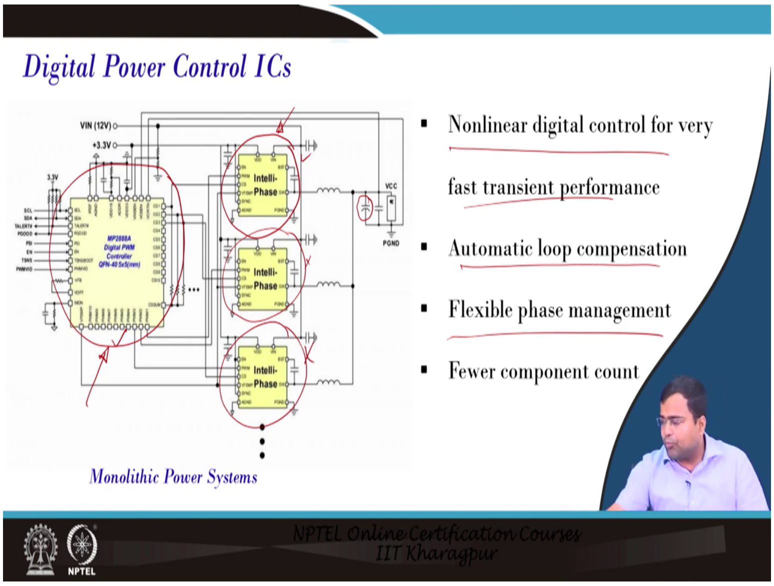

Another IC says I am showing the MPS Monolithic Power System solution where this is the digital controller IC which is a centralized controller and this is for multiphase applications. Where the number of phases can increase significantly it can be 8 phases, it can be 4 phases and each phase has a half bridge switch cell with a driver integrated along with the current sensor.

As you can see the current monitor's current sensing is coming out of the IC. So, these particular phases are optimized in terms of their capacity; that means, they can you know handle 30 and more than that ampere continuous current and the peak current can be even high and you need to balance all these phases. Because phase current balancing is important and that is done by this controller IC. Then you need to do phase shifts shifting so that the ripple of the output capacitor can be reduced so that the capacitor size can be reduced.

And third, also you need to do dynamic phase shading when the load current decreases. So, you need to maybe discard one of the phases and you may need to consider only one phase if it is under light load. So, all these algorithms mean this IC also uses a non-linear algorithm because it needs to achieve ultra-fast transient.

Particularly when you go for VR 13 and VR 14 specifications which specifications are not publicly available, but they are very stringent applications the undershoot overshoot requirement is very very low very stringent, and also the transient required time may be a few cycles.

So, to meet a such requirement may be linear control may not work. So, either you have to go for non-linear control or we can go for large signal base tuning on control, which can meet such requirements. Otherwise, the small signal-based control will not be sufficient. Then this control since will also have a combination of large signal and small signals. So, under a small signal, this IC can operate like a constant on-time control where you know there can be automatic loop compensation.

Because to you know to balance this current we need to adaptively vary the on time, then to meet a transient requirement or maybe phase shading. So, this automatic loop compensation is possible and also you need to ensure that you can meet certain desired switching frequencies. So, you need some automatic loop compensation.

Then flexible phase management is useful to achieve high efficiency for a wide range of load current and input voltage. And then since it is a digital control all this controller component algorithm everything inside the digital IC. So, you can reduce the component count and you can improve the power density.

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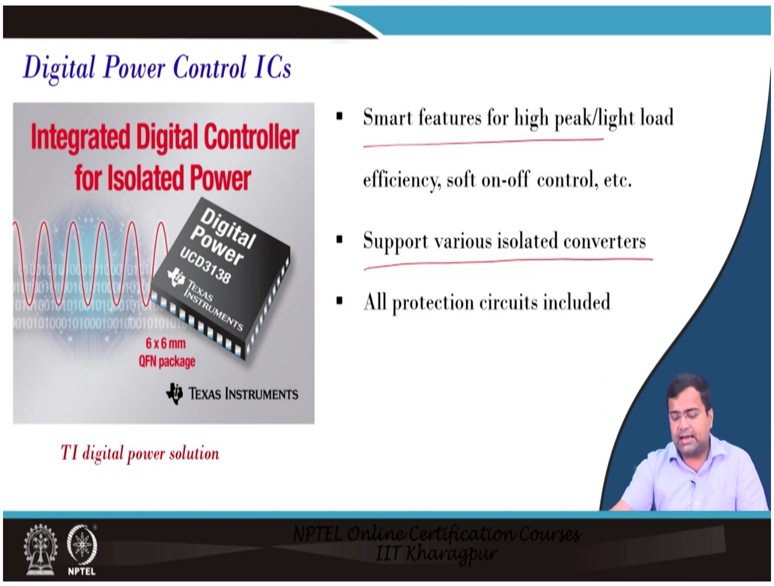

Another example is you know the Texas instrument digital controller this is particularly UCD 3138, this controller IC is used to control the isolated DC-DC converter one IC can control multiple isolated converters at a time, and also the same IC can be used to control various other isolated converters.

So that means, this offers a smart feature for high peak and load high light load efficiency, it will have a soft on-off control soft start also and it supports various isolated converters that I have discussed and this also includes all protection circuit

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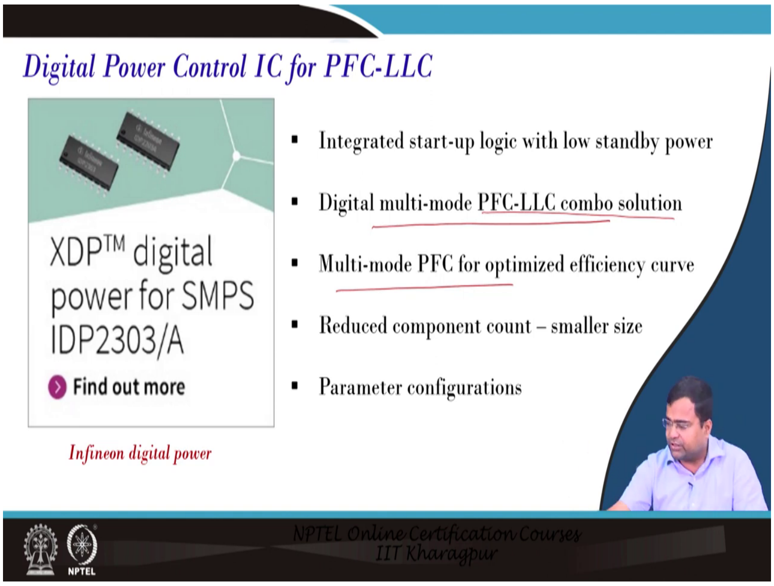

Now so far we have discussed the integrated solution where either it can be a digital integrated controller or it can be a digital power management IC.

But now we are talking about another example the digital controller IC for PFC LLC, particularly for LED driving application for display application and this particular IC actually can control both PFC and LLC together. So, it is a combo solution it has the integrated start startup logic with low standby power and it uses digital multimode control and it is used for a combo solution of PFC and LLC.

So, this multimode control enables us to achieve high efficiency over a wide load current range, and in this course, we will be going to demonstrate multimode control along with the hardware case study using FPGA implementation. And multi-mode PFC is optimized it can optimize efficiency for a wide range of load currents then because of digital control everything is inside the IC. So, reduce component count. So, the smaller size and the parameter can be configured using hardware software and firmware integration so; which means, you can tune the parameter from outside.

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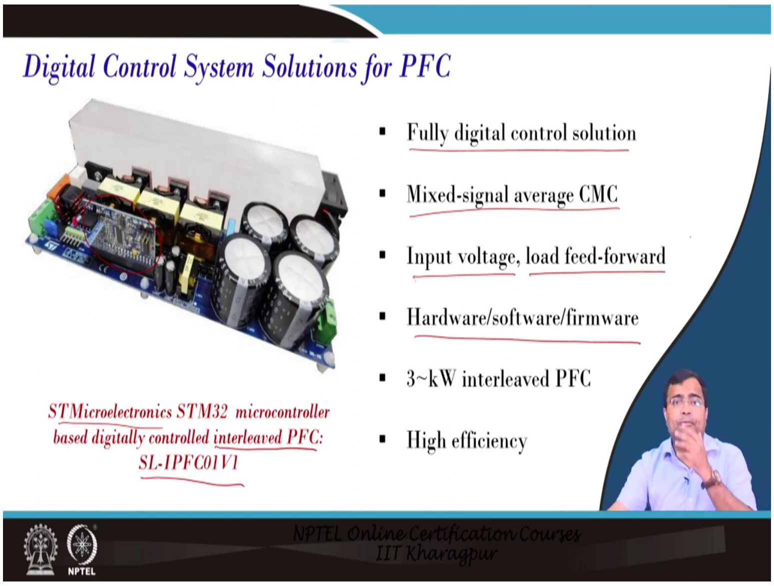

Now, we are going to a digital control system solution. So, one example is the ST microelectronics and which is for PFC interleaved PFC solution, where this is part number one can go to the reference design. So, this particular IC use a digital controller which is the STM 32 microcontroller and in this course, we will be going to demonstrate how to implement digital control using STM 32 microcontroller.

So, this particular reference design uses a fully digital control solution, where it uses a mixed signal average current mode control. So, in this course again we are going to demonstrate what is the architecture of mixed-signal current mode control. Then this IC uses input voltage feed-forward. Input voltage feed-forward is necessary because we need to achieve a unity power factor.

So, the shape of the reference current should follow the rectified input voltage. So, that is why input voltage feed-forward is essential and this IC also uses a loaded feedforward, because if you want to achieve a very fast transient response. And this particular solution also offers hardware software firmware integration. So, this design demonstration is for 3 kilowatts interleaved PFC and it also offers very high efficiency.

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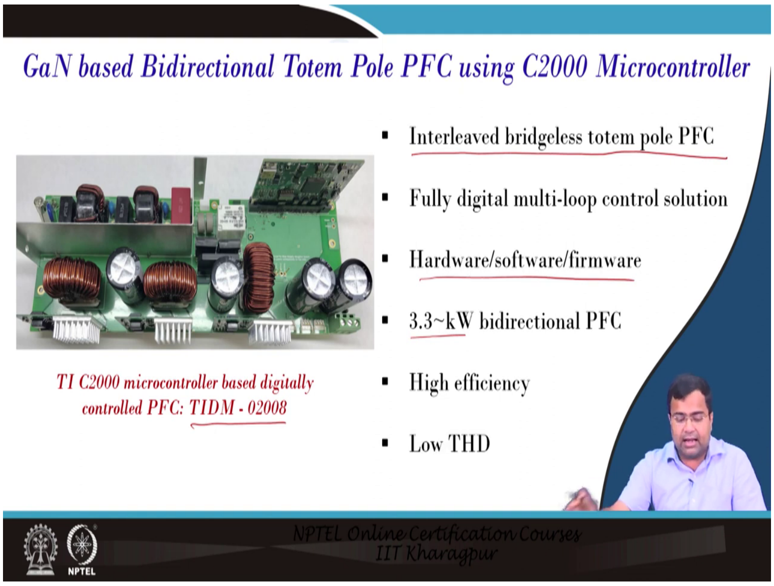

Another solution is a GaN-based bidirectional totem pole PFC using a Texas instrument C2000 series microcontroller. This reference design will be demonstrated you know particularly as an example case study because we will be considering C how to implement digital control using a C2000 series microcontroller.

So, one case study at the end will be this particular reference design of GaN-based totem pole PFC here it is an interleaved bridgeless totem-pole PFC and it is a fully digital multi-loop control solution and again it has hardware software firmware integration and this design for 3.3 kilowatts bidirectional PFC. So, by that means, this is used for particular vehicle-to-grid and grid-to-vehicle integration and then it also offers high efficiency and low total harmonic distortion.

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So, in the example, I have shown what is the benefit. The digital control since it is used let us say a microcontroller base or any other digital control and particularly I have shown some IC which can be used for different topologies. That means, the design can be made flexible, so that you can use it for varying topologies.

Then if we go for HDL-based implementation which will be talking in this course, you can make the design portable for other process technology. And I have told you that IC can accommodate large signal and small signal-based control for very fast transient response and high efficiency. So, the controller can be reconfigurable.

Then you can communicate because now it is coming with PMBus communication; so that means if there are multiple power converters you know particularly for let us say a mobile phone or even electric vehicle applications even for charger applications you need to communicate with the external devices.

Because you are taking charging from outside or if you are plugged into an AC grid or you are your charger is connected to the battery. So, you need to know the actual battery SOC status; that means that requires real-time communication and that is very much possible when your converter itself is working using digital control because this inherently provides digital data communication.

So, in this way, you can make the design reliable, and fault-tolerant, and the power supply network can be smart. And because of the digital solution, you can have a hardware software firmware integration, so you will get an optimized solution. And you can also interface with third-party solutions and you can achieve high efficiency by playing with a multi-mode solution and lower component counts because everything all the components is inside the digital control IC.

And you can implement advanced control logic, like digital non-linear control, and large signal-based control to achieve a very fast transient response along with a small signal control. Then you can have a digital power management IC solution or you can have a digital control IC for example, a multi-phase that controls multiple phases, and you can have a system-related solution which can be a microcontroller for controlling PFC or LLC.

And digital control can help initial development time very fast rapid prototyping using FPGA initially you can develop a microcontroller. So, it can reduce the technology development as well as the product development time.

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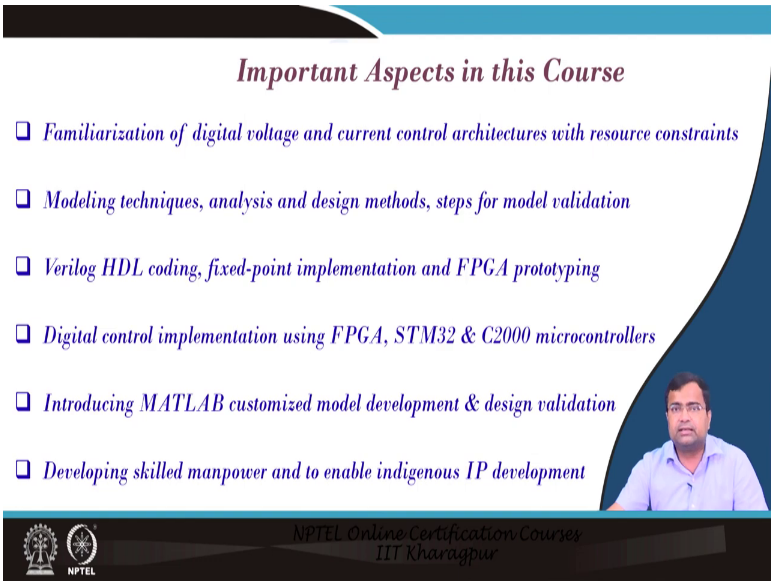

And this course particularly is useful to familiarize different digital voltage and current mode control architectures under resource constraints, then we will discuss different modeling technique analysis and design methods and we will also discuss steps on how to validate the model. Then we will also discuss and demonstrate Verilog coding and fixed point implementation and FPGA prototyping we will also discuss different digital control demonstration case studies using FPGA devices as well as STM 32 and C2000 series microcontrollers.

And we will also introduce MATLAB customized model and also we will show the step for design validation finally, this course will be helpful to develop skilled manpower and enable indigenous intellectual property development.

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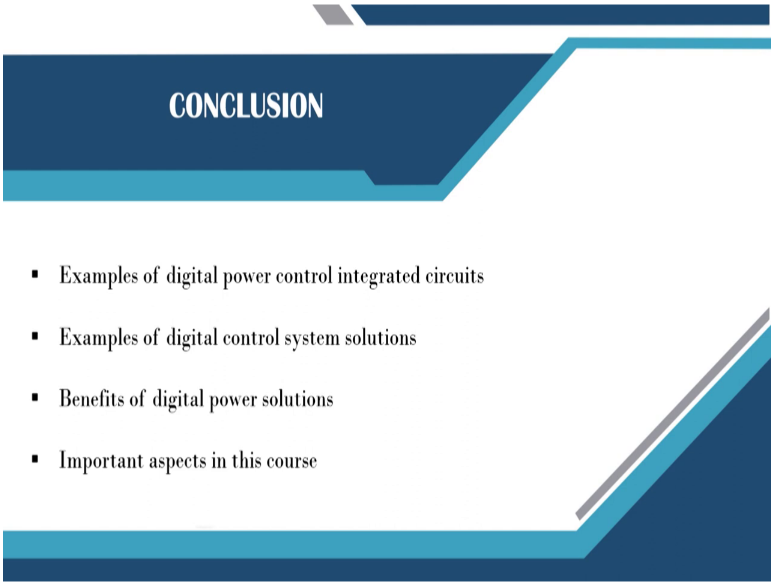

So, in summary, we have discussed some examples of digital power control integrated circuits. We have discussed some examples of digital control system solutions, we have shown the benefit of digital power solutions and we have also discussed. What are the important aspect of this course and how this course is going to benefit you know particularly industry practitioner as well as you know startup entrepreneur as well as researcher who is working on power electronics? That is it for today.

Thank you very much.