Integrated Circuits and Applications

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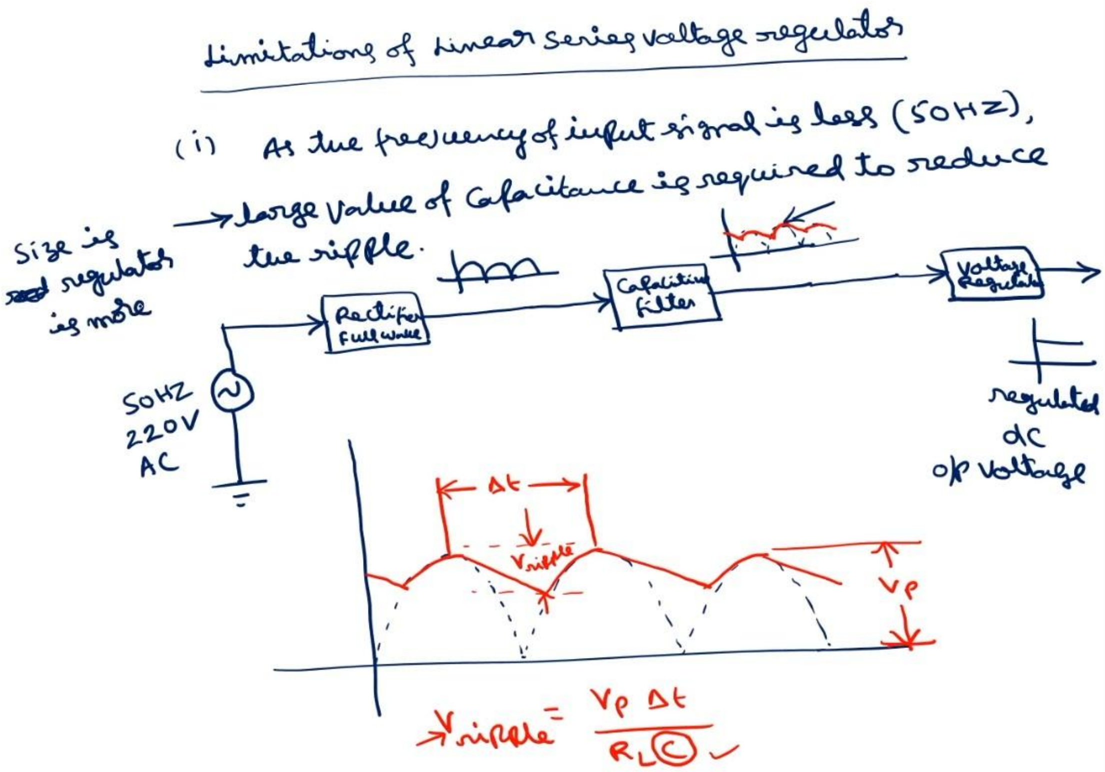
Voltage Regulators
Lecture – 36
Switching Regulators

In the last lectures, we have discussed about the series voltage regulators. So, in that we have discussed about the fixed voltage regulator and adjustable voltage regulators. So, the basic principle of this fixed or the adjustable voltage regulators is we will use this series power transistor in linear mode. There are some limitations of this series linear voltage regulators because we are going to use this power transistor in linear mode. So, the various limitations of this linear voltage regulators are as follows. The first limitation of this linear series voltage regulator is as the frequency of the input signal is less, normally *50Hz*.

Large value of capacitance is required, large value of capacitance is required to reduce the ripple. That is, we know that in case of a voltage regulator, normally, we will use this *50Hz* signal from the AC source. And, we are going to connect to a rectifier. If it is a full wave rectifier, we will get the output waveform like this.

Then, we will pass through the capacitive filter, so that the output of this capacitive filter will be having ripples. This is a type of output, we will be obtained from capacitive filter. Then we will get the output which is almost a DC with some ripples. And, we are going to apply to the voltage regulator. Then we will get regulated DC supply, here in order to reduce these ripples.

The relation is if I take this diagram. So, this is the full wave rectified output signal, and then this is the output of the capacitor, capacitor charges and discharges. There will be some ripples; if this voltage is V_p, the V_p voltage, this voltage is V_{ripple}, and between this peak to peak time duration is Δt. And, the $V_{ripple} = \frac{V_p \Delta t}{R_L C}$, here R_L is the load resistor. So, here in order to reduce this V_{ripple} we have to use large value of capacitance.



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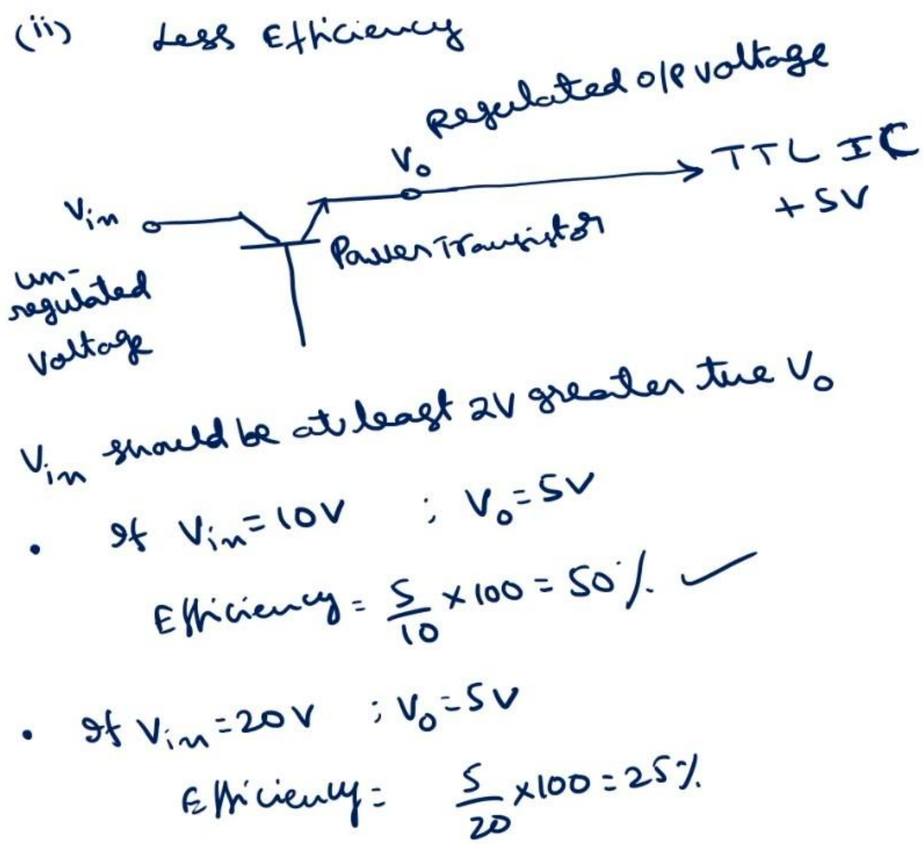
So, large value of capacitance means the area or size of this regulator will be more. So, this large value of capacitance implies size of regulator is more. This is one of the limitations of linear series voltage regulator. The second limitation is this will have less efficiency. So, efficiency is here defined as the output voltage by input voltage.

So, we know that in case of regulator power supply this is the series pass transistor which will acts as a emitter follower. Here V_{in} which is unregulated power supply, unregulated voltage is applied here. And, here, this is V_0, this is regulated output voltage, this is power transistor. And we know that this V_{in} is at least *2V* greater than output voltage. Suppose if I want to connect this output to the TTL IC.

So, we know that TTL IC will operates a with a voltage of *+5V*. If input voltage is, say, *10V*, if output voltage is *5V*, then the efficiency is $\frac{5}{10} \times 100 = 50\%$. On the other hand, if input voltage is *20V* and output voltage is *5V* efficiency is $\frac{5}{20} \times 100 = 25\%$. So, at the most, we can have 50% efficiency in case of a series linear voltage regulator. This is the second limitation of the series linear voltage regulator.



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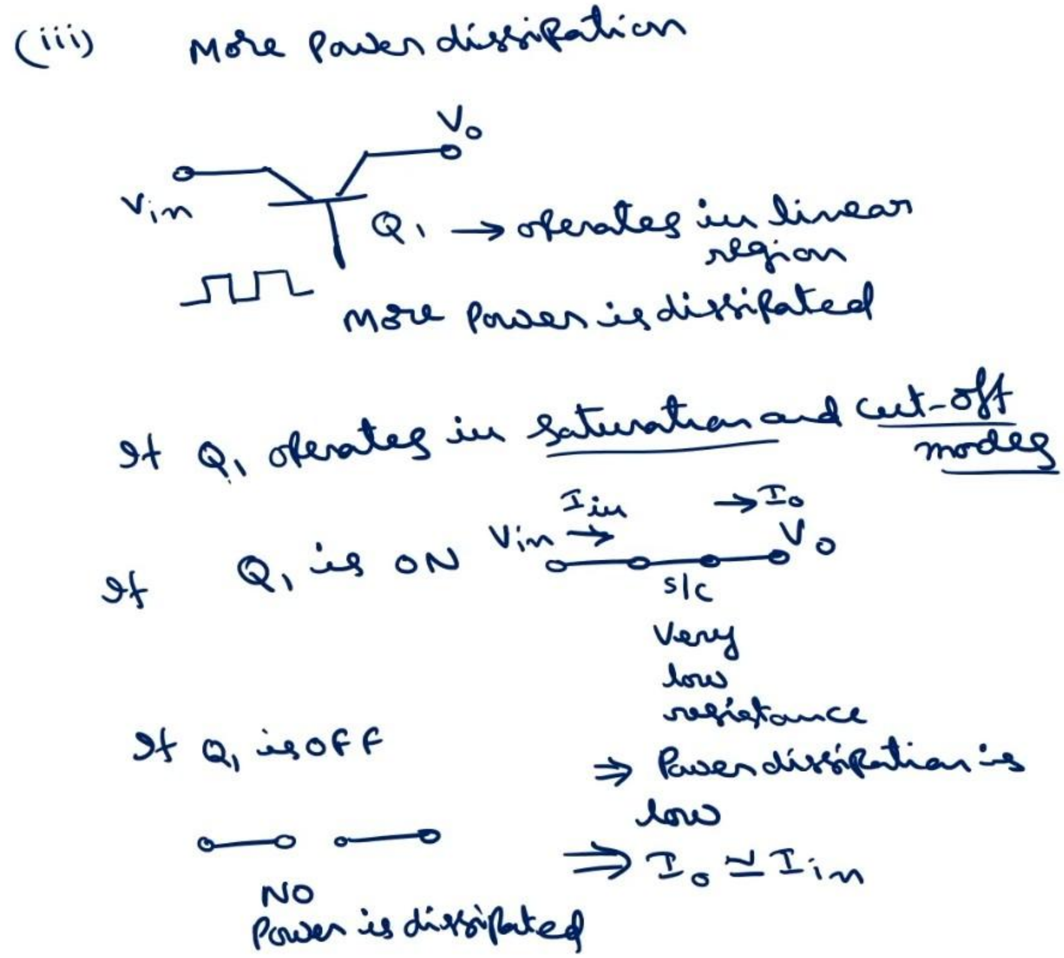
Third limitation is more power dissipation. Because this transistor always operates in the linear region. More power is dissipated in the transistor. Whereas, if I use this in the switched mode instead of operating in the linear region, if I operate Q_1 saturation and cutoff modes. So, when this transistor Q_1 is on, this will almost acts as a short circuit between V_{in} and V_0.

Either short circuit or, at the most this, will be having very low resistance. Because of that, the current is very less, and the power dissipation is very low. As a result of that the entire input current I_{in} will be transferred to load. I_0 is approximately equal to I_{in}. The maximum current will be transferred and maximum power is also transferred.

If Q_1 is off, then this will acts as almost open circuit. As a result of that, no power is dissipated. Input for this one is in the form of pulses. Then the power dissipation will be less if we operate this Q_1 in saturation and cutoff modes. So, this principle will be used in switched mode power supplies.



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The next type of the power supply is called as Switched Mode Power Supply or SMPS or also called as switching regulator. So, all the limitations of this linear regulator can be overcome by using switching mode power supply or switching regulator. Here, instead of having the *50Hz,* we will operate at high frequencies of the order of, say, *40kHz*. Because of this high frequencies, the size of the capacitors will be less. Thereby the size of power supply will be less when compared with the linear power supplies. This was the first limitation of the linear voltage regulators.

Switched Mode Power Supply (SMPS):-
(or)
Switching regulator

✓ High freq : 40KHZ

✓ 70-90% Efficiency

✓ Less Power dissipation

- Personal computers
- Security and railway systems
- TV sets
- Motor drives

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The second limitation was efficiency is less whereas, here efficiency is more efficiency of this switched mode power supplies of the order of 70 to 90%. And the third drawback is switched mode power will be having less power dissipation compared to the linear regulators because here, the transistor operates in either saturation or cutoff regions. So, because of this regions, switched mode power supplies are more popular in many of the electronic appliances. So, we have lot of applications of this switched mode power supplies, especially in personal computers. We will use this switched mode power supply and we have in traffic secure and railway systems.

In television sets, we have switched mode power supplies you can use this for the motor drives also. This is more popular power supply when compared with the linear power supplies. If we consider the block diagram of this switched mode power supply, first it will take the input supply voltage normally *50Hz 220V*. This will be applied to the input rectifier and filter which we have already discussed in the previous slide. So, that you will get a DC output voltage which is not perfectly regulated, there will be some ripples will be there.

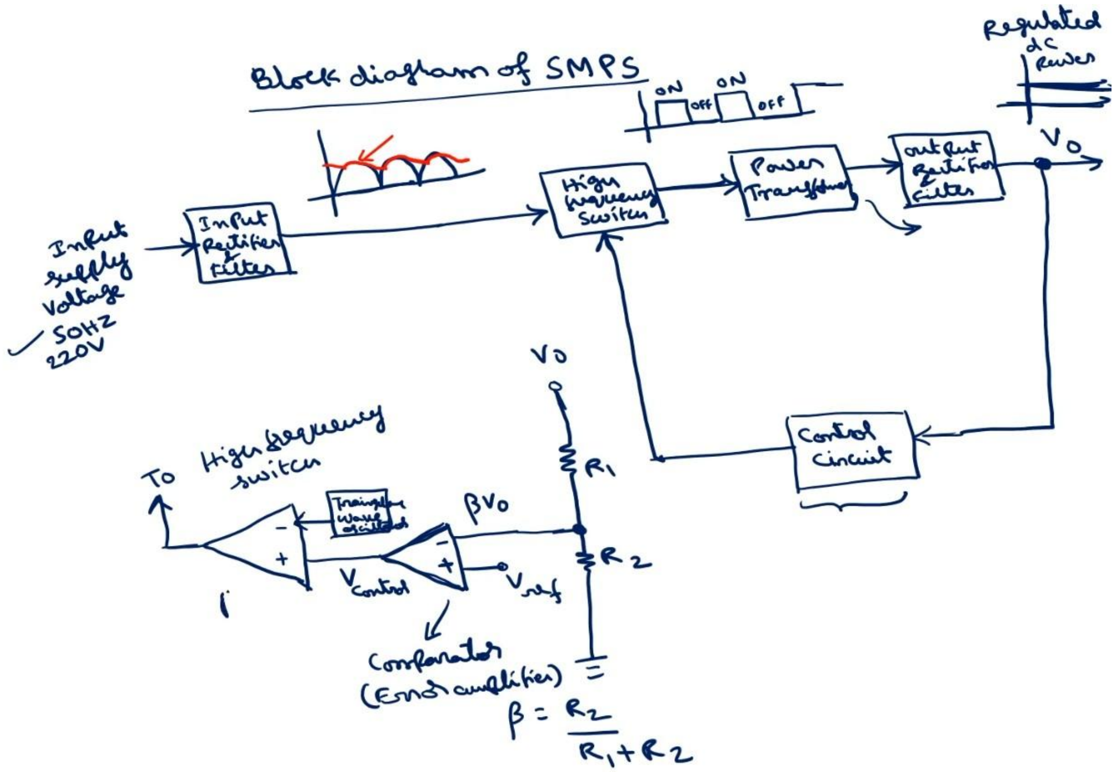
So, this type of output will be there this red color output and the output of this rectifier and filter. Now, this will be applied to a high frequency switch. So, that the output will be having output of this switch will be having high frequency rather than *50Hz*. Because of that, the capacitance values will be less, thereby, the size will be less. This high frequency switch output will be connected to a power transformer. This will be applied to output rectifier and filter.

So, that the output will be a regulated DC power supply. Then, a part of this one will be applied to the control circuit to nullify the variations in the output voltage due to a load current variations or input variations. So, this control circuit basically controls the on off durations of this high frequency switch. This is the overall block diagram of this SMPS which is a switched mode power supply. So, the output of this high frequency switch will be you have on and off and this is on, this is off, on, off.

So, alternative will be on and off depends upon the control voltage that will be generated by this control circuitry. Then this power transformer will step up the voltage, and this output rectifier will make this unipolar, and then it removes the ripples, thereby this will produce the regulated output voltage. If any changes in the output occurs, how do you apply it will regulate the output DC voltage, how does it nullifies the changes in the DC output voltage? So, for that, if I consider this control circuitry internal details. This consists of a comparator whose non-inverting terminal will be applied to the V_{ref}, and this inverting terminal will be applied to a part of this output voltage.

If I call this as V_0 and this V_0 will be sampled through the voltage divider similar to the linear series voltage regulators. Here, this will be beta into V_0 where $\beta = \frac{R_2}{R_1+R_2}$ and this is V_{ref}. So, this output will be applied to PWM that also can be implemented by using another operational amplifier. Here a triangular wave is generated, this triangular wave oscillator. Then this will produce a voltage which will be easy to control the high frequency switch.

If I call this, as $V_{control}$ voltage at the output of this comparator which will acts as the error amplifier, which we have discussed in the earlier lectures. Then, what will be the waveforms of $V_{control}$ versus this output of this PWM pulse width modulator? This is the triangular wave which is applied to the one of the input terminals of the PWM. $V_{control}$ is this one. Then what will be the output of this PWM? Between these points so, this triangular wave amplitude is greater than $V_{control}$.



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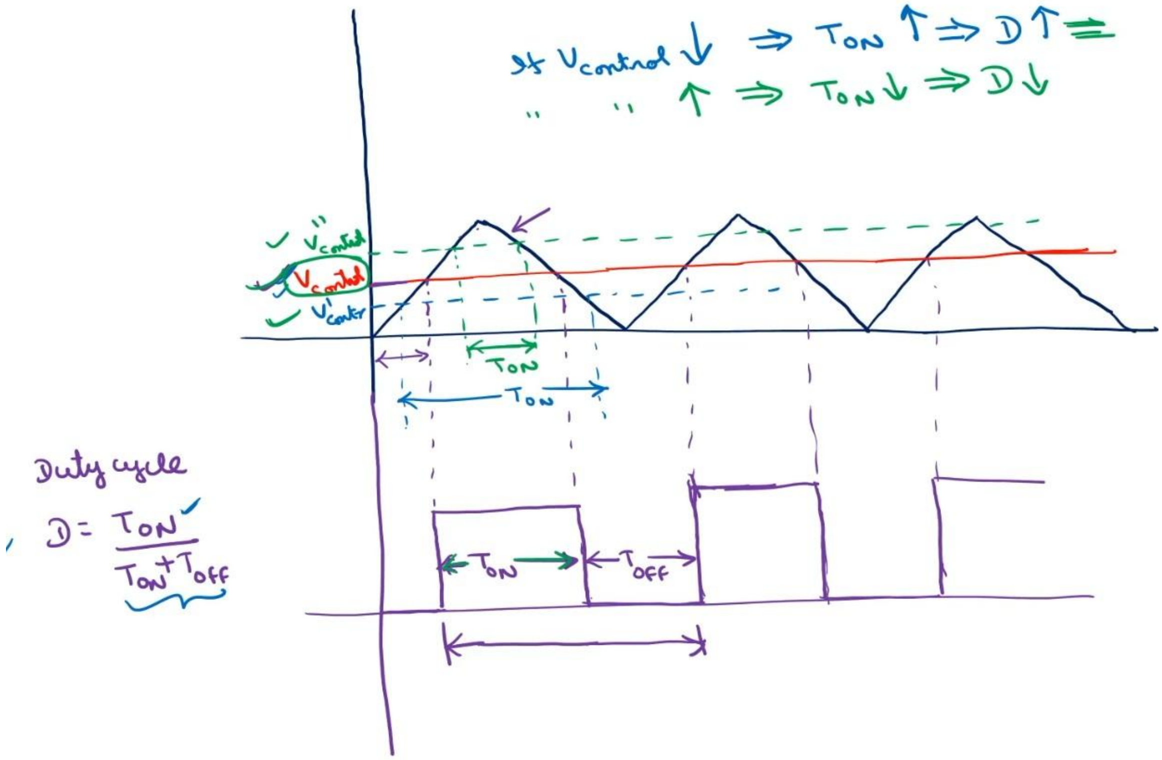
If I connect to this to place and this minus, then if the triangular wave amplitude is more than the $V_{control}$ voltage, then the output of this PWM will be a positive pulse. If triangular wave amplitude is less than $V_{control}$, then the output will be negative pulse. As a result of that what will be this one during this portion from here to here triangular wave amplitude is greater than $V_{control}$. So, we will get positive pulse, and from here to here triangular wave magnitude is less than $V_{control}$.

So, we will be having negative. In between here to here, see the angle of state here to here high state and so on. This is one complete period; this is T_{ON}, this is T_{OFF}. Duty cycle is defined as $\frac{T_{ON}}{T_{ON}+T_{OFF}}$. So, this T_{ON} duration will be controlled by this $V_{control}$. So, for this value of $V_{control}$ this is the duration of T_{ON}.



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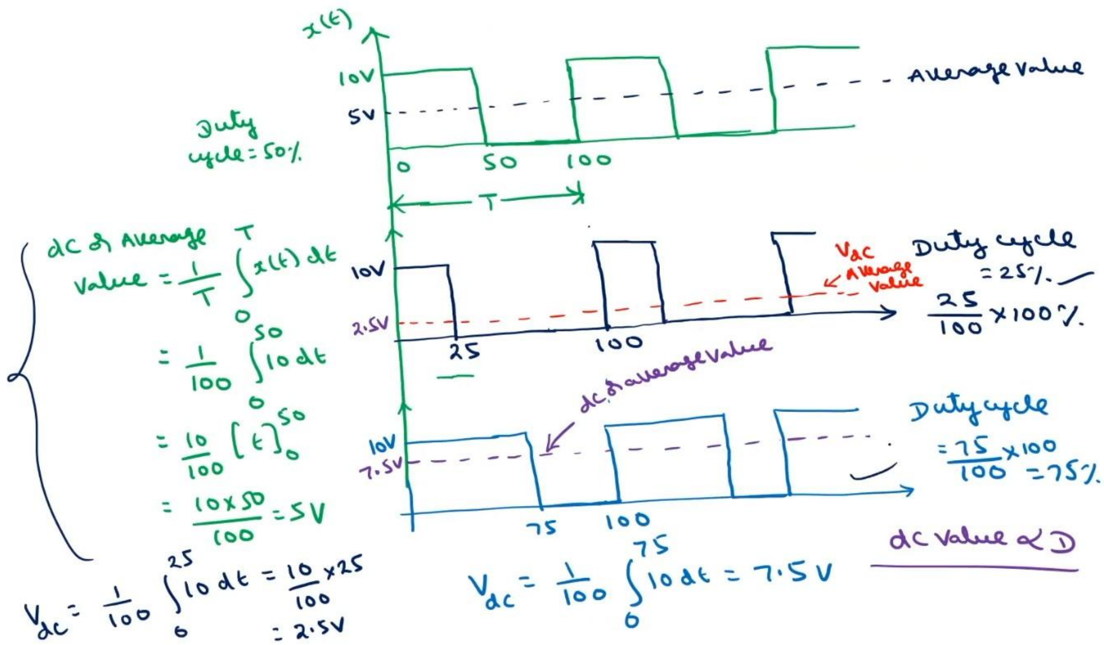
If I increase or decrease this *V_{control}*, suppose if I take this $V_{control}$, a value which is less than this suppose $V_{control}$ is somewhere here. What happens to this duty cycle? What happens to T_{ON}? T_{ON} will be now having more duration from here to here, this is T_{ON}, and T_{OFF} will be less. As a result of that, if you increase this $V_{control}$, if you decrease this $V_{control}$ compared to this $V_{control}$ is less because this has $V_{control}$ dash. Then what happens Ton is increasing. Thereby, duty cycle also will increases because $T_{ON} + T_{OFF} = constant$. So, T_{ON} if T_{ON} increases D also increases.

On the other hand, if I take a value which is less than this $V_{control}$, say this value, we call as $V''_{control}$. Then on time will be only this much this T_{ON} is this is less than this T_{ON}. So, if $V_{control}$ is increased from this reference $V_{control}$ value this is a larger value this is a lower value. If you decrease, then duty cycle will increases, if you increase this $V_{control}$ value implies what happens T_{ON}? T_{ON} decreases, thereby duty cycle also will decreases.

This is one of the important result ok. So, depends upon the $V_{control}$. If $V_{control}$ is more, the duty cycle will be less; if $V_{control}$ is less, the duty cycle is more. Now, how does this duty cycle will generate the DC voltage? I will consider three different cases duty cycle of, say 50%, then on time off time will be same. This is duty cycle is 50%. So, what is the average value of this one? If I assume that this is *10V*, this is 50, 0, this is 100. How do you find out the average value or DC value? $\frac{1}{T}$ time period here will be 100, integral 0 to T.

If the signal if you call as this as $x(T)dt$ is the expression for the average value or DC value of the given waveform ok. So, in this case what happen this is T is $\frac{1}{100}$, $\int_0^{50}$, this is , $10dt$ whereas, 50 to 100, 0 that integral becomes 0. So, this is equal to $\frac{10}{100}[t]_0^{50} = \frac{10\times50}{100} = 5V$. So, this is at the centre of this; this is the average value.

If I take two other different cases where duty cycle is less than 50%, greater than 50%. If you take the second case, if duty cycle is less than 50%. Here you can see that duty cycle is 25%, this is 25, this is 100, this is 8 and volts. On time is $\frac{25}{100}\times 100 = 25\%$, duty cycle is equal to $\frac{25}{100}\times 100 = 25\%$. Now, what will be the average value here? So, according to this formula, $\frac{1}{T}$ is $\frac{1}{100}$. Only integral 0 to T becomes 25. From 25 to 100, it is 0, and this is *10V* into dt. This is equal to $\frac{10}{100}\times 25 = 2.5V$. This average value will be somewhere here. If I take the third case, where duty cycle is more than 50%.



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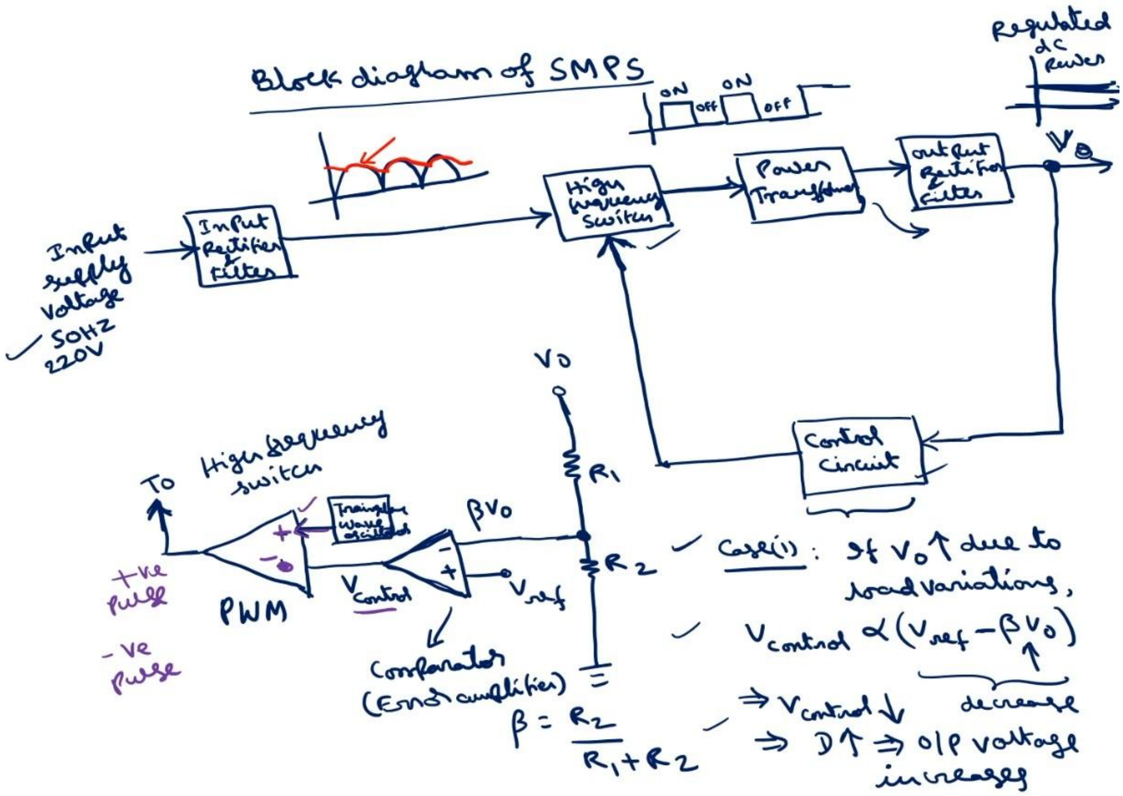
This is 75, this is 100, this is *10V*. You can see that on time is $\frac{75}{100}\times 100 = 75\%$. Now, what will be V_{dc} here? $\frac{1}{100}\int_0^{75} 10dt = 7.5V$. It is here this is the average value. So, here the conclusion is the $V_{dc} \propto D$.

If duty cycle is more, D_{CR} average value is also more. From the previous conclusion here is if $V_{control}$ decreases duty cycle increases, if $V_{control}$ increases duty cycle decreases. So, based on this if I come to the operation of this one. Suppose, if V_0 increases due to the load variations, then what happens? If V_0 increases then what happens to $V_{control}$? $V_{control} \propto V_{ref} - \beta V_0$. If V_0 increases, then the negative term increases overall. This value will be decrease, that is, $V_{control}$ decreases.

So, if $V_{control}$ decreases duty cycle increases. If duty cycle increases, then DC value also will increases. So, this output voltage is going to control this high frequency switch. So, which will reduce the variations in the V_0. Similarly, if V_0 decreases due to the load variations that will be compensated through the similar type of the action which you have explained for the case 1. So, in that way we can regulate the variations of the output using this control circuitry and high frequency switch.



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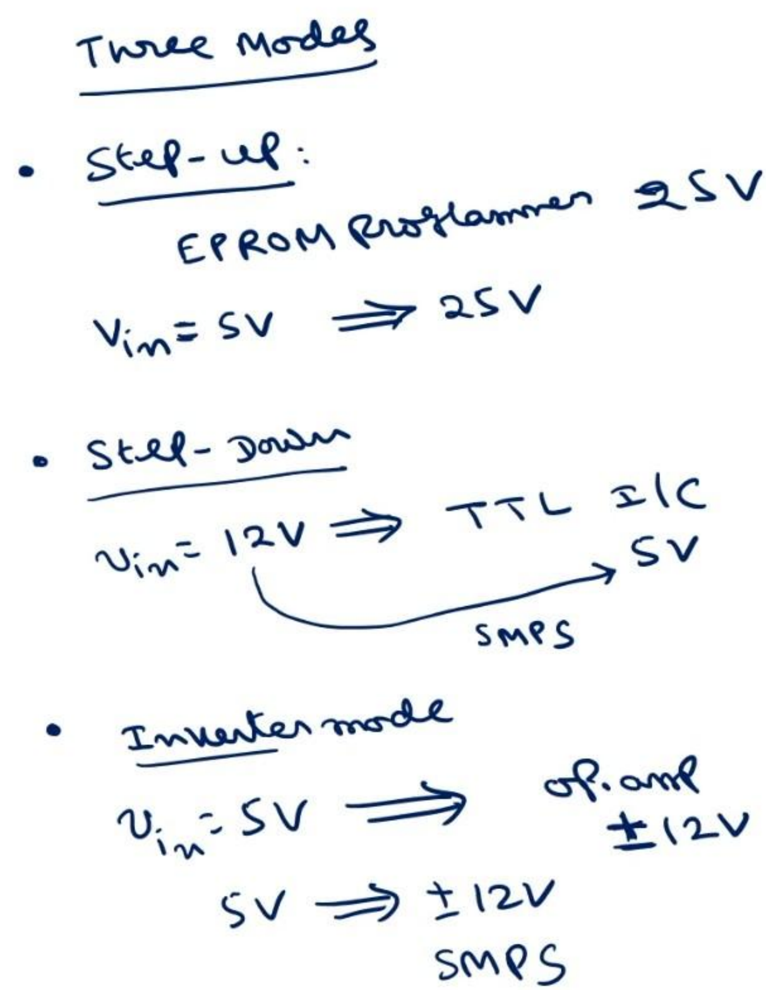
So, this SMPS can operate in 3 modes. One is step up. Suppose, if I want to use a PROM programmer which needs *25V*. So, the input voltage will take *5V*, then will step up to *25V* using this SMPS, and the second mode step down. Suppose the input voltage is *12V*, and if you want to control TTL IC, which requires *5V*, then you have to step down this voltage from *5V* to *5V*, *12V* to *5V*. This can be performed by using which should mode power supply. Third one is inverter mode. I have say input voltage is *5V*, and I want to control operational amplifier, which requires $\pm 12V$.

I want both the positive voltage as well as negative voltage. In such case, we will operate in inverted mode this *5V* will be converted into plus or minus *12V* using SMPS. So, you see about this switched mode power supplies. So, we have discussed about the fixed voltage regulator, which is linear and as well as adjustable and different to this linear regulators is switched mode regulator, where the transistor operates in saturation or the cutoff regions unlike the transistor operates in linear region in case of a linear regulators. Because of this saturation and cutoff regions, the SMPS dissipates low power, and it acquires a high efficiency of the order of 70 to 90%.



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Because of this advantages, most of the electronic appliances uses this switched mode power supplies. So, in the next lecture, we will discuss about the data converters. Thank you.