Power Electronics

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Lecture - 2

Hello, in my last class, we discussed the need for using electric energy very efficiently or the need for conserving electric energy and in case of induction machine which is a work horse of industry, we found varies ways of saving electrical energy. In case of induction machine to save energy, there has to be a separate power processing unit in between the source and the load. Just by connecting the source directly to the machine, it is just not possible to save electrical energy or it is just not possible to operate the machine where the efficiency is maximum. So, you have to or there has to be a separate power processing unit which process the power and which gives the required input to the machine. Now, let us see in the case of DC machine. DC machine has a very excellent control characteristics, it is very easy to control the torque. Armature current and field current are always there at quadrature, in 90 degree. Angle between i_a and i_f is always in 90 degrees. Therefore, torque per ampere is maximum. But then, we all know the disadvantages. It requires regular maintenance, it is not suitable for high speed applications and various other issues. See, all this limitations are addressed in the induction machine. Induction machine is a very rugged machine. It is capable of running at high speed. But then, whatever the advantage that we had in DC machine, just not there. It is very difficult to control or torque control of induction machine is difficult.

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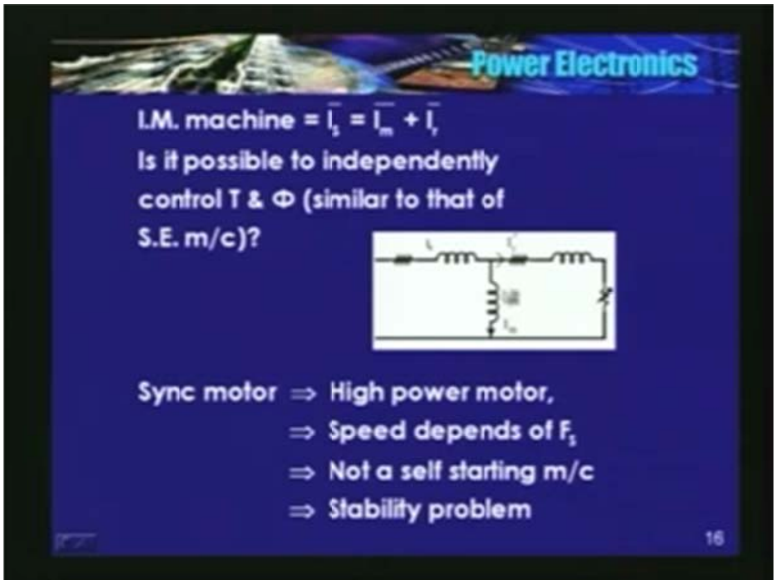

See, in this equivalent circuit the rotor current, equivalent rotor current and magnetizing current, vector sum of these two is a stator current. So, whatever that happens in the rotor circuit will affect the magnetizing current and therefore the stator current. In DC machine? Yes, the rotor current and field current, they are always at 90 degree. So, we could control them independently.

Now the question is, can I design some sort of a controller in which I can get the characteristics similar to that of DC machine from an induction machine? So, I have almost, I have achieved everything. Induction machine is very rugged, all the disadvantages of DC machine are addressed here or eliminated. So, here is the control scheme along with the power process unit. I can get the characteristics of separately exited DC machine from an induction machine. Is it possible? We will see whether it is possible or not.

By the way, so far I have not told you the definition of power electronics and goal of power electronics. I will just tell you the various avenues in which you can save electric energy. Then towards the end of my lecture, let us see whether or using power electronics, can we address all this problems. May be answer, may be very obvious one.

So, we discussed induction machine and let us talk about the synchronous motor. Generally, high power machine but then, it is not a self starting motor. So, our machine teacher told us that one of the way to start a synchronous motor is, start like a induction machine using a cage winding and excite the field when the speed is approximately is equal to this synchronous speed or when it attains a greater speed, close or excite the field winding, machine will pull into the synchronism. What is the problem here? There is a stability problem, in the sense, if there is transient loading, if the machine is suddenly loaded, it may fall out of step. In this machine, the rotor speed is determined by the supply frequency. See rotor, the speed of synchronous machine is always equal to the synchronous speed and synchronous speed is governed by the supply frequency. So, in other words, the supply frequency determines the speed of rotation that in case of the conventional synchronous motor connected to a three phase supply. So, can I address the stability problem? See, instead of making rotor speed depends on the stator frequency or stator field, can I generate the stator frequency from rotor speed? See I will repeat, I am generating the required stator frequency from the rotor speed. So, in case, there is a sudden transient loading on the rotor or on the machine, rotor will decelerate. So, automatically there should be a reduction in the stator frequency. So, if that happens, there is no stability problem at all. Synchronism is always assured. Is it possible to implement this scheme? What is other avenue in drives? See, we are talking about energy conservation. Take for example; I have a high power machine, running a high inertial load, high inertial load, J is very high. Now, you want to stop the motor. You want to decelerate it and bring it to halt. So, if you put out the supply which is the natural thing to do, what will happen? Since, J is very large, machine will take a longer time to decelerate and come to a halt.

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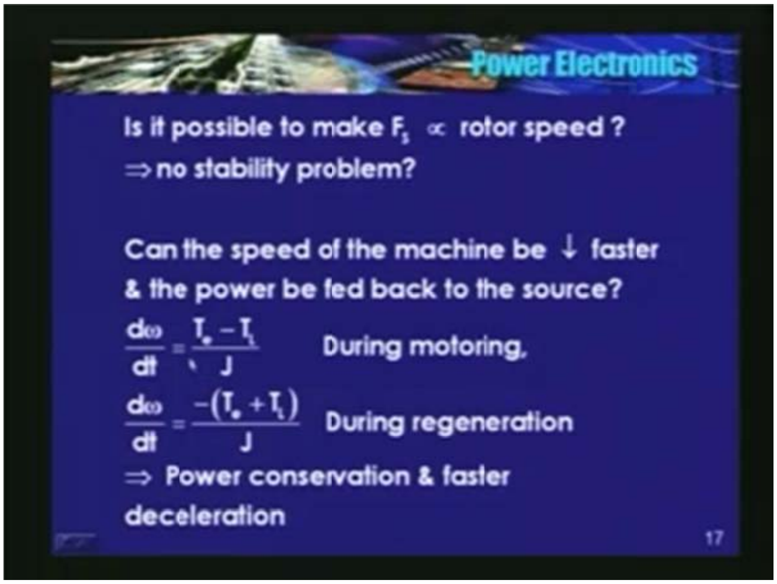

See the equation, this is the equation. J d omega by dt plus b into omega is equal to T minus T_L. Where, t is electromagnetic torque developed, T_L is the load torque. So, if I neglect the friction, d omega by dt is given by T minus T_L divided by J. So, if I put off the supply, may be electromagnetic torque will be zero. So, machine will decelerate depending upon mechanical time constant, all the energy that is stored in inertia is dissipated as heat and machine takes a long time to come to a halt. We are talking about energy conservation instead of dissipating the energy stored in the inertia. Can I recover it and feed back to the source? Simultaneously, can I increase the rate of deceleration? Right, like you know killing two birds in one stone, one is recover the energy which is stored in inertia and feed it back to the source and increase the rate of deceleration.

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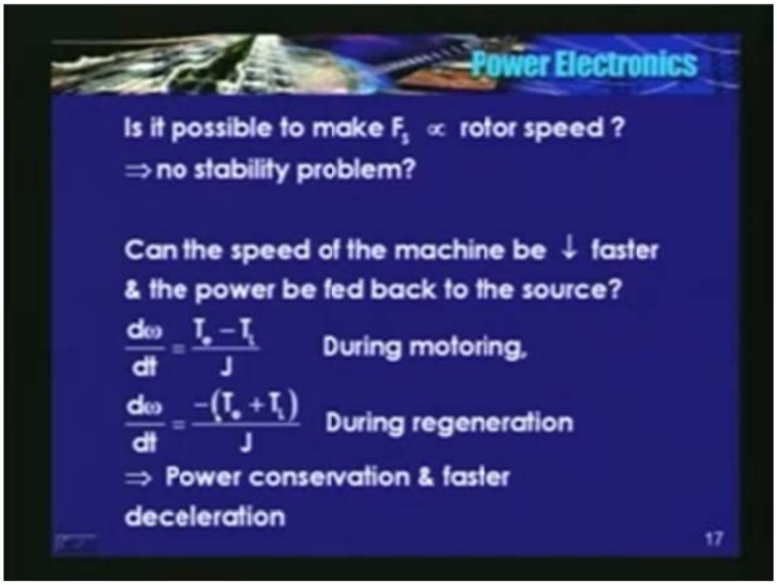

See here, d omega by dt is maximum when I do like this, T_e plus T_L divided by j. I have made it T_e negative now, so if T_e is positive for motoring action, T_e negative implies a generating action. So, by making T_e negative, I have increased the rate of deceleration. Now, de omega by dt is T_e plus T_L divided by J. T_e is negative it implies that generating action energy is fed by this source. So, is it possible to do this or to implement this? We will see later. Now, coming to the DC power supply that is used in the laboratory, the regulated DC power supply, in a digital electronics we require 0 to 5 volts, in analog electronics, may be depending upon the biasing voltage for a BJT or op amp, it could be plus or minus 5 or plus or minus 12.

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See, here is a regulated power supply. 30 volts, dual regulated power supply, 30 volts, 2.4 amperes equivalent to 2.5. So, wattage is approximately 150 watts, dual power supply, 150 watts. See, it is heavy, quite heavy and there are some devices and there is a heat sink and some transistors are mounted outside, looks like for heat dissipation. They must be getting hot, that is why they have mounted it outside with the large heat sink and quite heavy. This is what we are using or you might have used in a laboratory, regulated DC power supply. Why it is so heavy?

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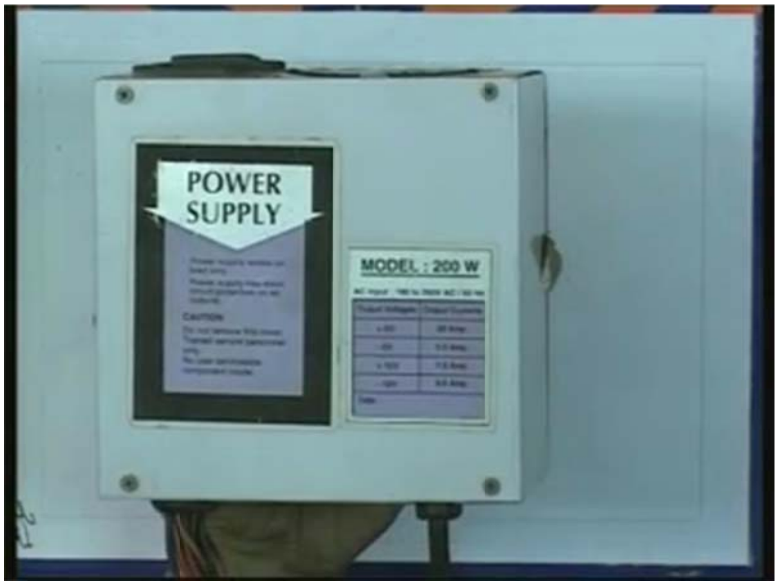

See here, another power supply which is used in computers, 200 watts. I can carry it safely in my palm, so light. Why it is so light? 200 watts and the power supply that I showed you is 150 watts and there is nothing like a heat sink outside and some transistor or some devices outside. There is only a input AC supply and these are the outputs. Why this is so light and why this is so heavy? It is so heavy because there is what is known as a very weak element. That is a 50 hertz step down transformer. So, we must, all the regulated power supply that we have using in the lab, has a 50 hertz regulating transformer, step down transformer. So, can we eliminate this transformer, thereby reducing the size, weight and power supply?

See, when I was a student, may be in 90s, the speed of the PC was 20 mega hertz. PC 80, it was suppose to be a state of the art machine, 20 mega hertz PC 80. Now, the speed is of the order of say, 2.4 giga hertz or so. May be higher, I do not know. The speed of the Pentium machine or the speed of the computer is increased, definitely there are IC's. So, as the clock speed increases, definitely some of them, some of the IC which are there must be operating at that speed. So, as the clock speed increases, may be some of the IC's have to switch or change the state at that rate. There is something known has a switching loss take place and this losses, they increase with frequency, the switching frequency. Now, one way is to reduce the clock frequency which is just not possible, all of us want very fast machine but then I have to reduce this losses. How do I reduce the losses? Another way to reduce the losses is to reduce the biasing voltage itself. Because, when the output is high, the output of the T_{TL} may be V_{CC} and if the output is low, it becomes zero. So, can I reduce the biasing voltage itself? See, I was told that two years down the line, the biasing voltage will come down to as low as point nine volts. So, two years down the line the power supply requirement is point nine volts, 100 amperes DC power supply. Point nine volts, 100 amperes DC power supply, can we design this power supply, using a step down transformer and what not? Is it possible or do we need all together different techniques? We will see.

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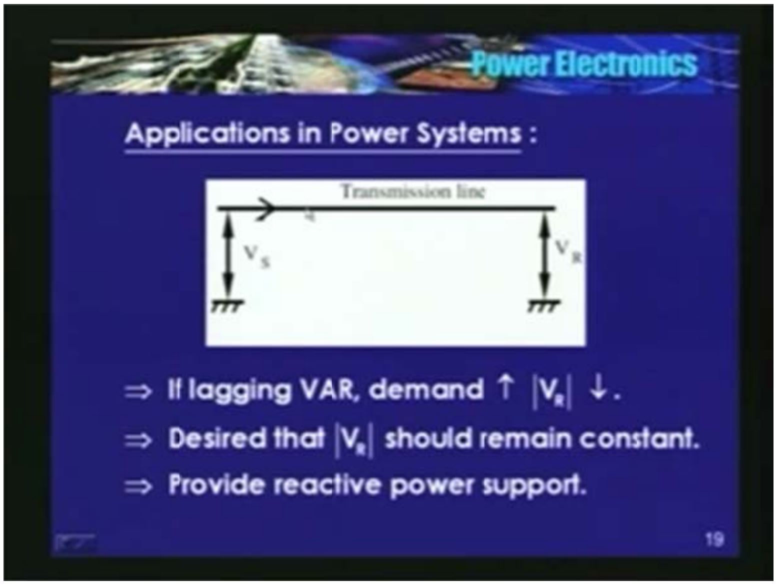

Now, coming to power system, here is a single line diagram, a long transmission line. I have not shown the parameters, the transmission line parameters. Here is a sending end voltage, V_S is sending end voltage. Length to the transmission line is very high, I can consider as a long transmission line which you might have studied in a power system course and here is the receiving end voltage, V_R is a receiving end voltage. It is expected that or it is required that V_R remains constant. V_R remains constant, approximately one per unit it remains constant. It is desire, but then we find that voltage at the receiving end generally falls with load and this V_R, magnitude of V_R is much less compared to V_S as the lagging VAR demand increases.

In other words, if the power factor becomes very poor, lagging power factor, a large inductive load is being connected here. You will find that the difference between V_S and V_R is high. In other words, if I keep V_S constant V_R drops. So, if the lagging VAR demand increases or in other words, as the power factor angle increases that is lagging power factor angle increases, the magnitude of V_R falls. Now, how do I improve the voltage profile at the receiving end? In another words, how do I maintain V_R at one per unit or how can I maintain that V_R a constant value. I told that one of the reason for V_R to fall is the reactive power demand has increased. The transmission line is feeding a large reactive load.

So, one of the ways to improve the power factor which our circuit theory, we learnt is that to connect a capacitor at the receiving end. In other words, you connect a capacitor here. So, this capacitor will supply the required lagging volts to the load. So, therefore the source will now, transmission line or this current is only a unity power factor current. There is a unity power factor current, the entire demand reactive demand is met by the capacitor. Now, I have connected a capacitor to supply the reactive power demand of the load. Voltage at this point is falling. So, as this voltage falls, the VAR supplied by the capacitor also falls.

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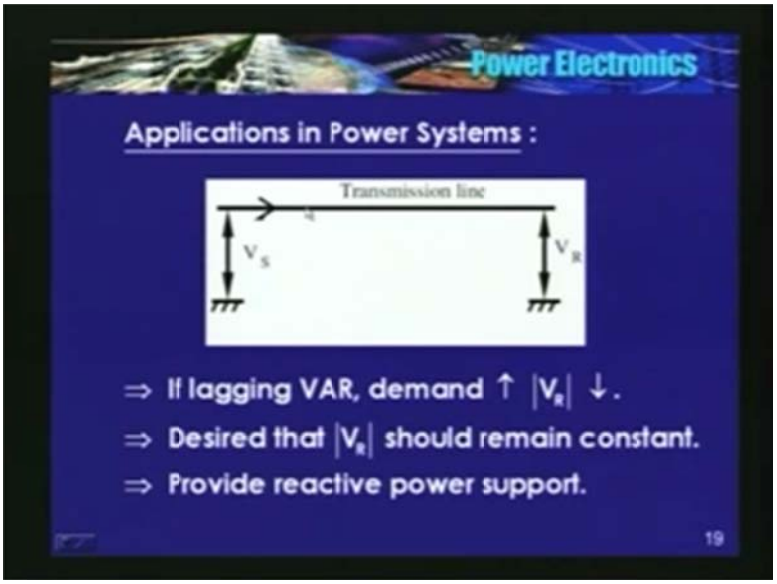

See, because it is given by this, Q is V_R square divided by X_C. I have connected C at the receiving end and Q is V_R square divided by X_C. So, as V_R falls, Q also falls. What is required for the transmission line? As Q_R falls, sorry as V_R falls, Q should increase. See, I will repeat, for transmission line as V_R falls or voltage at the receiving end falls, Q should increase. Only then it will try to maintain the voltage at the required value. But here I have connected a capacitor and we found that as this voltage at the receiving end falls, the Q supplied by the capacitor also falls. So, some sort of an unreliable friend. When you want that friend's help, he is just not there. Same thing is happening here. A capacitor is supposed to supply a higher Q as V_R falls. But then as V_R falls, the capacitor VAR also falls, an unreliable friend. What is the second thing? You have to vary the capacitance in order to vary Q and a smooth variation in C is just not possible. It is going to be in steps.

So, the question is can we design a circuit which supplies both plus or minus Q VARs, lagging VARs as well as leading VARs and it is independent of V_R voltage at the receiving end? I will repeat, can we or is it possible to design a circuit where in, it should be possible to supply plus or minus Q very smoothly, smooth variation of Q and it should be independent of the voltage at the receiving end or voltage at V_S? Is it possible? The question that I am asking, we will see sometime later, the answer to this question.

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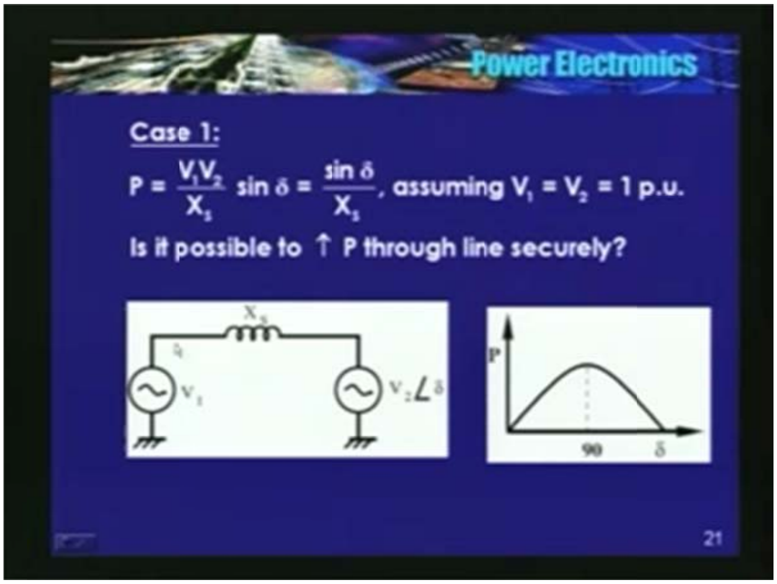

The second case in power transmission, consider again a transmission line. I am just representing a transmission line by the reactant X_S. Some reactance, I have called it has Xs. So voltage at this point I have maintained as V_1 and voltage at this point is V_2. I am taking V_1 as the reference and angle between V_1 and V_2 is delta. So, what is the power transmitted through this transmission line? It is V_1 into V_2 divided by Xs into sine delta. This is the expression that we have derived. Where, V_1 and V_2 are the voltages at the two ends of the transmission line, Xs is the inter connecting reactance and delta is the phase angle difference between V_1 and V_2. Now assume that V_1 and V_2 are 1 per unit. Now, how did I achieve to get V_2 is equal to 1 per unit, we will see later. Now assume V_1 and V_2 is equal to1 per unit. So, get P is equal to sine delta divided by Xs and again, here is a profile P verses delta and we have told from this equation, we can find that variation is possible, theoretical variation. Theoretical limit is delta is 90 degrees. Delta is 90 degrees that is theoretical value. May be in actual practice, this delta could be of the order of 30 to 40 degrees. In actual practices, the delta angel between two ends is of the order of 30 to 40 degrees. 90 degrees is just on the black board or on the note books that is all. Now the question is, is it possible to increase P power transmitted to the line securely? Can I increase the power transmission, the power that is transmitted to the line securely?

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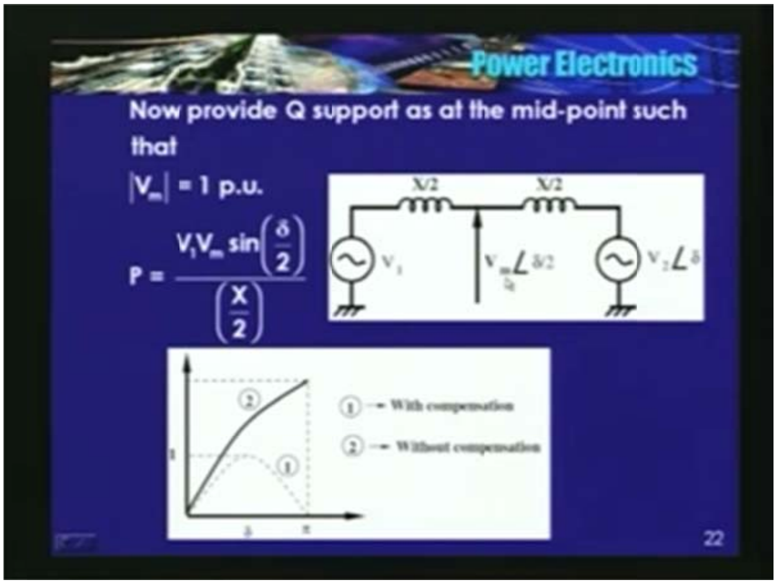

Take this example, it is the same thing, say V_1 at the end of the transmission line, V_2 at other end of the transmission line, delta is angle between V_1 and V_2 and at the midpoint, somehow I am maintaining a voltage V_m which is 1 per unit. See, somewhere at this point by supplying only the reactive power, I am just connecting a reactive element here. I am just connecting a reactive element here and making the voltage at this point, midpoint of the transmission line is one per unit. So, there is no active power transfer to the device here. It is just the reactive power transfer. I am just supplying Q at this point, at the center point. Same condition, voltage at this point is one per unit. Now, I can find that angle between V_1 and V_m is delta by 2, a symmetry. So now, what is the power transmitted through this line? Same power will go through this point. It is V_1 into V_m divided by the reactance between it, it is X by 2 into sine delta by 2. So, this is the expression.

Now, I will plot. In the previous case, theoretical limit is 90 degrees. Now you just see, when delta is equal to pi, it is at the peak, theoretical limit again. So, it is possible to transmit a higher power through the existing transmission line by providing some sort of a reactive power to support at the midpoint of the transmission line.

Now, what exactly is its unit or what is to be or what is the role of power electronics to achieve this? Again, we will see later. Again a third application, again in power systems we have a long transmission line. Generally, power that is produced in rural areas, the remote end and bulk is consumed in the urban areas. So, you require a real long transmission line and the moment there are long transmission line, there are various problem, stability problem, voltage drop. Now, can we address this problem? See, instead of transferring the power that is, whatever that is generated directly to the receiving center or to the urban place, can we convert the AC power to DC? Convert the AC power to DC, transmit it, transmit this DC power and again at the receiving station you invert to AC because, power that is utilized almost all the loads, they require AC. The power generated also may be AC. But then, if I transmit the AC power; there is a problem, stability problem, voltage problem.

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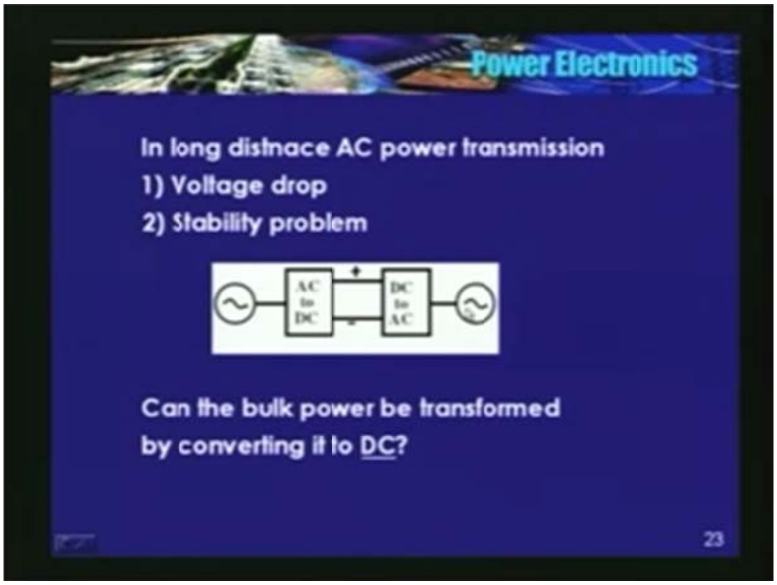

So, what I will do is, this AC power we convert it to DC, how? Again, I am not answering that question nor I am telling you how exactly to do this right now. There are only two wires, positive DC bias and negative DC bias. In AC we had three transmission lines. Now, there is only the resistance of the conductor that will come into picture and this DC, I will convert it back to AC and in this case let me tell you one thing, there is no stability problem at all. So, this scheme is known as high voltage DC transmission. So the question is, can the bulk power be transmitted by converting into DC? I will repeat, can we transfer bulk power by converting it to DC? Answer later. Now, that is about power that is being consumed by motors and we discussed the various issues in power transmission. The third point or the lighting, I said bulk is consumed by motors and second is by lighting.

We all know that lumen for what, for an incandescent bulb is much lower compared to that of a florescent lamp. Lumen for a bulb is very less compared to lumen for florescent lamp or for a tube light. What is the problem in the florescent lamp? Bulb, we just require a holder and a wire. What do we require here? We require a ballast or what is known as a choke and a starter. Why do you need a ballast or a choke is because, the lamp has a negative characteristics once the arc has been struck. So, I will not go in to detail of working of the florescent lamp, I am just telling you that the lamp has a negative characteristic, negative impedance characteristic, negative resistant characteristic. It operates at 50 hertz, it requires a choke or a ballast. Invariably, a magnetics that is used at 50 hertz, they create a objectionable noise that is irritating, because it is in the audio range, they are noisy and over all power factor is again poor. What is the another effect? There is something known as stroboscopic effect because lamp being is turned off and ignited at every 100 second, at every zero crossing. That is something known has a stroboscopic effect. So, this could be objectionable or it could be dangerous in the shop floor because say, assume that there is a blade which is rotating at the same speed and both the frequencies match, what will happen? The rotating blade appear as if it is stationary. So, it could be dangerous. Actually it is rotating but it appears to be stationery, so it could dangerous. So what is found is the lumen output of the lamp increases if the frequency of operation has increased. As the frequency of operation increases or if the lamp is operated at a higher frequency, the lumen output also increases.

Now, the frequency of operation is high, the size of the magnetics or storage elements also comes down. So as frequency of operation increases, the size of L that required or may be … all, if at all require, all come down and we all know that if the frequency is above 20 kilo hertz, it is above the audible range, you can hear the noise produced. So looks like, there are advantages by operating the lamp at a frequency higher than say, 20 kilo hertz or so. One is it is in the audible range, above the audible range you cannot hear that noise, lumen output is also increased, size of the magnetics has come down, also it is possible to improve the source site power factor.

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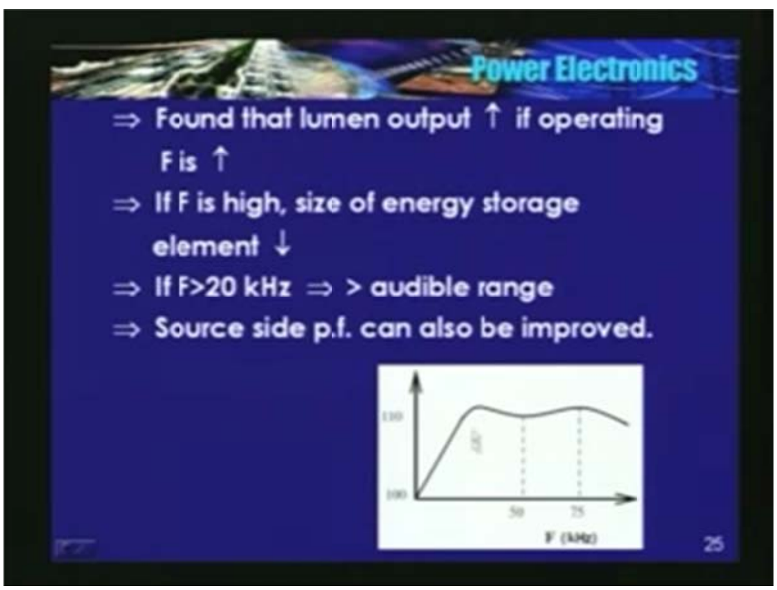

I will just show you the plot of the lumen. This is a lumen output verses the frequency. This frequency is in kilo hertz, not hertz. We have only 50 hertz supply. I have plotted for kilo hertz say, may be 100 at a very low frequency of 50 hertz. 50 hertz, it could be around 100, attains a peak around say, 20 kilo hertz or so. So again, we have a 50 hertz supply and here I need to operate at 20 kilo hertz. Somewhere I need a frequency converter that is about light.

So far, we discussed about the issues or avenues wherein to save power or to transmit more power or to improve the power transmission capability, we need to have a separate equipment. Now let us see energy from the alternate sources because in order to extend, whatever the life period that I have told you so called 200 years, I have to use, one way to use it, very efficiently another way is to look for other alternative sources.

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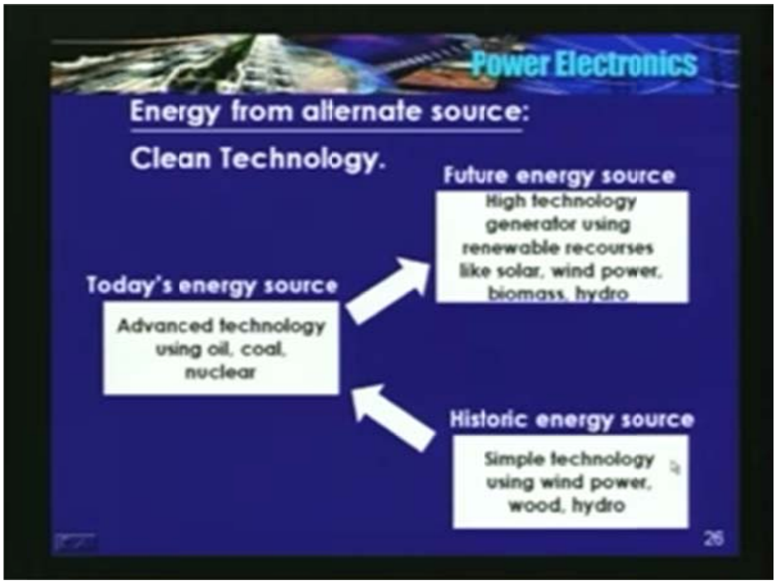

See, here is an overall picture, the energy form nonconventional sources or the renewables. See, if we go back to the historic energy sources, our ancestors, forefathers, they used a very simple technology. They used a very simple technology, using wind power, wood and hydro. A very simple technology used to produce power. Slowly we transformed to today's energy sources. We use oil, coal and nuclear. Just know I told you that these power stations are invariably located at remote end that has been transferred to the load centers, generally the urban places.

The future trend is going to be what is known as the distributed power generation, in the sense, if there is a demand you set up a small power plant there itself instead of generating power, may be around at three to four hundred kilometers away and transmitting it. So if you want, if there is a small load center, you set up a small plant using renewables and try to feed the local area, what is known as the distributed power generation that is going to be the future. So again, the future is going to be using renewable sources like solar, wind power, biomass, hydro. Say, it looks like wheel has completed its one round. See, we were here, our forefathers did this, they also used wind power, hydro, the future is also been projected and it is true, it will be true. It is going to be solar, wind power, biomass, hydro, future and this historic. Looks like one complete circle or wheel has completed its circle. But then, what are the issues here?

Fine, in the sense, solar and wind, they considered to be very clean. But, we all know that solar is bit expensive but the silver lining cost is falling, it is decreasing, cost per unit is decreasing and the other problem with solar is the output is DC. It is DC power output and most of the loads except for the incandescent bulb may all require AC. How about wind? supposed to be very cheapest, environmentally clean.

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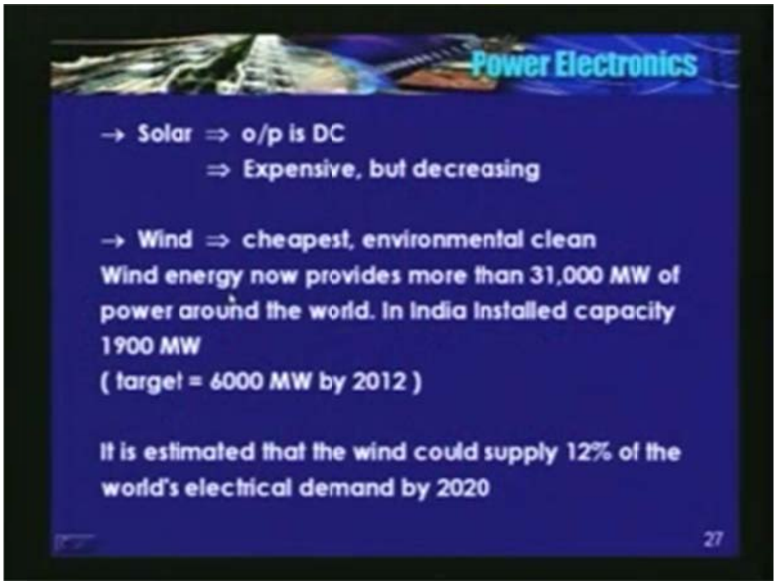

See, it is projected that, see here, this what reported in the literature, wind energy now provides more than 31000 mega watts of power around the world, this is reported in the literature. In India the installed capacity is 1900 mega watts. Installed capacity is 1900 mega watts in India, is nothing new to us and our target is to achieve 6000 mega watts by 2012 and it is also estimated that wind could supply 12% of the world's electricity demand by 2020. It can supply world's 12% demand by 2020, just the projection that is projected. But then, what is the problem here? Solar is DC, something definitely you need to have one more power processing equipment. Wind, we all know that it is highly unreliable. See, that is problem with the nonconventional sources solar, unreliable. On the cloudy day there could be no power at all. Wind, again it is a seasonal, fine even if it is a seasonal, what are the problems there? As the wind speed changes, there is a turbine, the speed at which the turbines is rotating, the rotor of a machine also changes.

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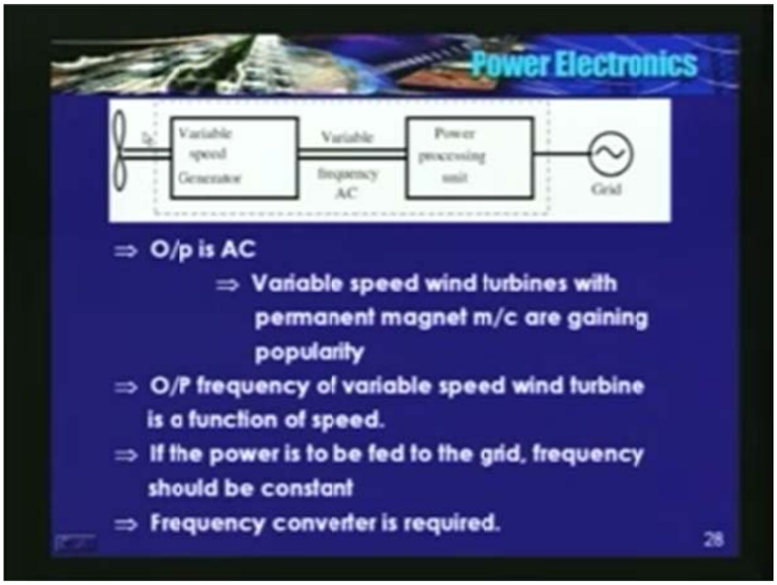

See the plot diagram here, this is a variable speed. Therefore, the magnitude of the voltage as well as the frequency is a function of the wind speed. Like you know, the conductor is rotating magnetic field, voltage induced in conductor is propositional to the speed of rotation or the relative speed and second is the frequency also depends on the speed. So, at this point we have a variable frequency AC source. Grid requires a constant voltage and constant frequency source. You cannot have a grid where the frequency and voltage varies over a wide range but here is a wind speed varying over a wide range. So definitely, there has to be some sort of a power processing unit. What is this power processing unit? We will see sometime later.

See, there are directly grid connected induction generators. But then now days, so called a fixed speed, the moment I connect an induction generator directly to the grid, the speed, the centre frequency is determined by the grid. So, the rotor speed also is fixed now, it should be higher than higher than the synchronous speed. But then now a day's, the variable speed wind turbines with permanent magnetic machines are gaining popularity. They have become increasingly popular, variable speed wind turbines, see here. Variable speed wind turbines with permanent magnetic machines, they are gaining popularity, increasingly becoming popular. So, what is the problem here? Again, I told you just now, output frequency and the voltage is the function of speed, magnitude is the function of speed. This requires constant frequency, constant voltage. So you require a power processing unit. What is that power processing unit?

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Last one, urban pollution can be decreased by the wide spread use of electric vehicles. Instead of having vehicles which are operated in gasoline, you have electric vehicles or say high breed electric vehicles. So, if you use electric vehicles or high breed electric vehicles, there is going to be significant reduction in urban pollution. Here, we all know that gasoline based vehicles are efficient at a particular speed. So, what I do is operate the IC engine at that particular speed and other speeds motor driving the wheels. So, thereby you can reduce the pollution as well as save the fuel. So, that is about the various avenues whereas you can either save energy or try to make a difference in improving the quality of life. There are many more still left. Now, before discussing those issues I will give you definition and goal of power electronics.

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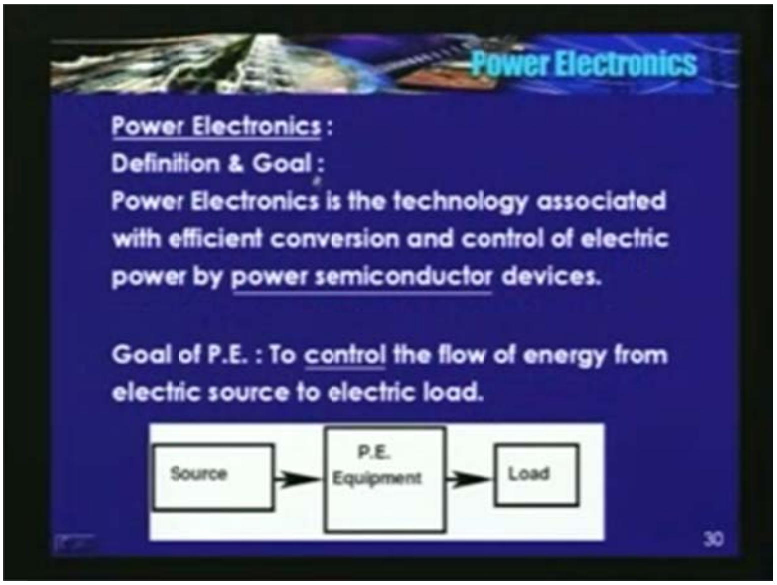

See here, Power Electronics is a technology associated with efficient conversion and control of electric power by power semiconductor devices. See I will repeat, power electronics is a technology associated with efficient conversion and control of electric power by power semiconductor devices. What is the goal of power electronics? It is to control the flow of energy from electric source to electric load. See, here is the block diagram. There is a source, here is the load, inter facing is done by the power electronic equipment. So, depending upon the nature of the source and nature of the load, this equipment or the configuration also changes. Why the power electronic is so popular? Why it is being compared with computers?

I said, two technologies will dominate, one is computers and other one is power electronics. Why it is being said that power electronic is an enabling technology for distributed power generation? I told you the future is going to be distributed power generation and power electronics is the enabling technology for the distributed power generation. Why it is being said that power electronics provides the life blood for communication equipments, electronic systems and computers or in other words why this is so popular? See, the success of any technology, it depends on the following; it should be highly efficient, second is it should be reliable, third the size, weight and cost should be low. Say, may be unknown to going against the law of nature because it may not be possible to achieve all these factors like high efficiency, high reliability, size, weight and cost low or that very difficult to achieve all this factors.

Let us see, which are the factors that can be achieved, take for example, what happens if efficiency is high? See, if the efficiency is high, it implies that there is low power loss. If there is low power loss, cooling requirement or the heat sink requirement comes down. As the power loss is low, the temperature rise is also low. So, I can package the various elements very densely. In other words, packaging density can be increased. If the packaging density increases, size comes down. So, if I try to achieve high efficiency, I can achieve other parameters also. Looks like, the efficiency of this power supply unit must be very low, that is the reason it is so heavy and there is a large heat sink and components are being mounted outside. It is heavy, whereas the

efficiency of this must be high that why it is become so small, compact and so light. So, how this power electronics achieves this? We will see it in next class.
Thank you.