Power Electronics

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Lecture - 1

Power Electronics

Hello, I am B.G. Fernandez. I am with the department of electrical engineering, IIT Bombay. For another forty lectures or so, I will be dealing with various aspects of power electronics. Now, what is the definition of power electronics and what is the goal of power electronics, I will tell you sometime later. Power electronics is one of the basic courses in electrical engineering. It is a very interesting course, an important course and relatively easier to understand. So, all 3, in 1 course, very interesting, very important and relatively easy to understand. So, it is a very basic course in electrical engineering, it can be termed as course on circuits. I will be using Kirchhoff's voltage law, that is KVL, Kirchhoff's current law, that is KCL and behavior of inductor and capacitor for DC excitation and AC excitation. So, these are the prerequisites. Definitely, all this topics you would have studied in your eleventh or twelfth standard.

Having said, that power electronics is a basic course, to appreciate this course, you need to know or you need to have reasonably a good knowledge on circuit theory, good knowledge on electrical machines, power systems, power semi conductor devices, little bit of device physics. So, if there are devices, definitely you need to know, little bit of analog electronics, digital electronics, control theory and microprocessor or micro controllers. So, in this sense, power electronics is a multi disciplinary course. So, little bit of almost all the branches and all the subjects in electrical engineering is been covered or you need to know the various topics to appreciate this course. So, I will not talk much on this course, I expect you to explore more about it, during the course. So, the outline of the course, I have divided into 6 parts.

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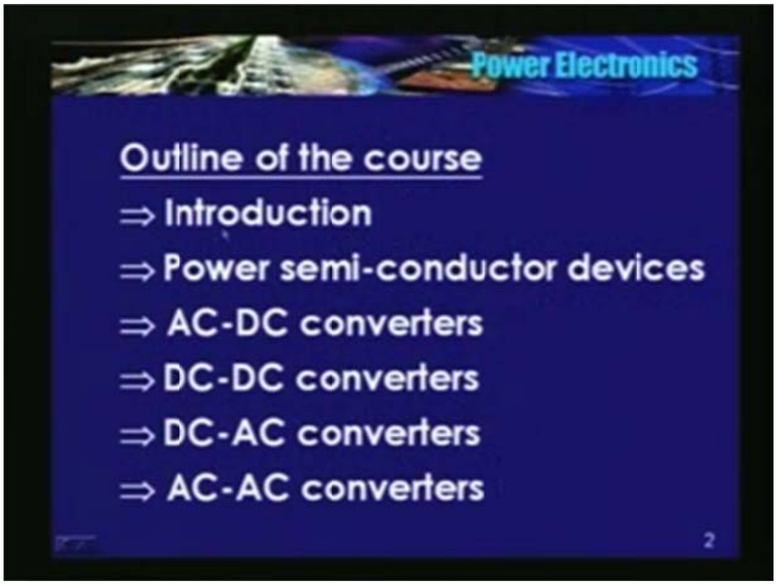

One is introduction, second is power semi conductors devices. Power semi conductor devices, they are termed as the heart of power electronics. I will repeat, power semi conductor can be termed as heart of power electronics, is that important, then various circuits in power electronics. They can be classified into broadly four areas. One is input is AC, output is DC. Second one is input is also DC, output is also DC. So, DC to DC converters. Third, input is DC, output is AC. DC to AC converters and last one, see we have here, DC to DC…. There will be AC to AC converters also. Input is also AC, output is also AC. So, we will study these various converters in detail. Simultaneously, we will study where exactly these converters are being used in real time or real life situation. Various books that I am referring are these.

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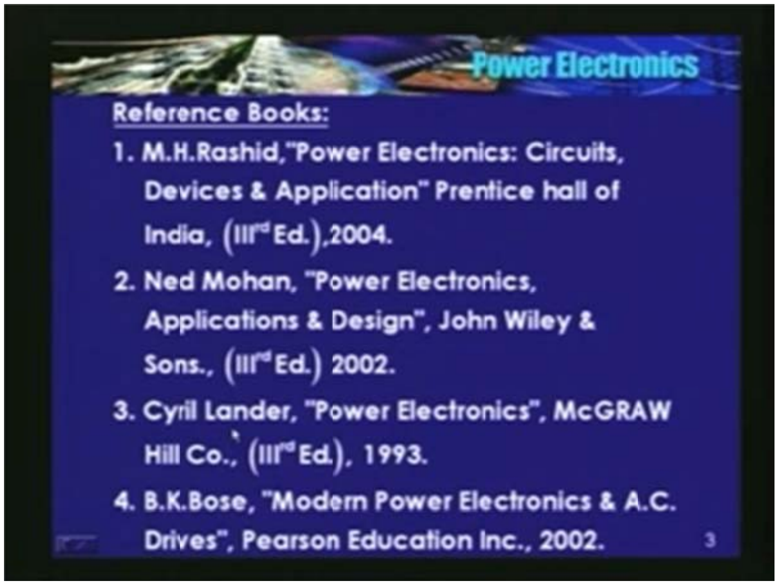

I have just given them in alphabetical order. First one is M. H. Rashid, title is Power Electronics: Circuits, Devices and Application, published by Prentice hall of India. Third edition is the latest one. It is published in 2004, third edition 2004. Second one is Ned Mohan. There are three authors, one of them is Ned Mohan, title is, Power Electronics, Applications and Design, published by John Wiley and sons, third edition in 2002. Third book, Cyril Lander, title is Power Electronics, published by McGraw Hill company, again third edition, year of publication is 1993 and the fourth one, B.K. Bose, title of the book is, Modern Power Electronics and A.C. Drives, Pearson education 2002.

So, these are the four books that I have referred. Other than that, I have referred the papers which are published in international journals. Apart from these four books, there are other books also. There are a lot of books available on power electronics. Now, before telling you about or giving you the definition of power electronics, I will just show you the codes, that appeared in international reputed journals of power electronics. There are basically four IEEE journals. One is IEEE journal on Power Electronics. Second is IEEE journal on Industrial Applications. Third is IEEE journal on Industrial Electronics. So, first one is Power Electronics, second is Industrial Application, third is Industrial Electronics, fourth is Power Delivery.

So, I am just showing you some of the course that are published or appeared in these journals. So, just want to tell you, to publish a paper in these journals, there is a rigors review. So, after reviewing, paper just accepted and it is being published in those journals. I am just showing you some of the course that appeared in those journals.

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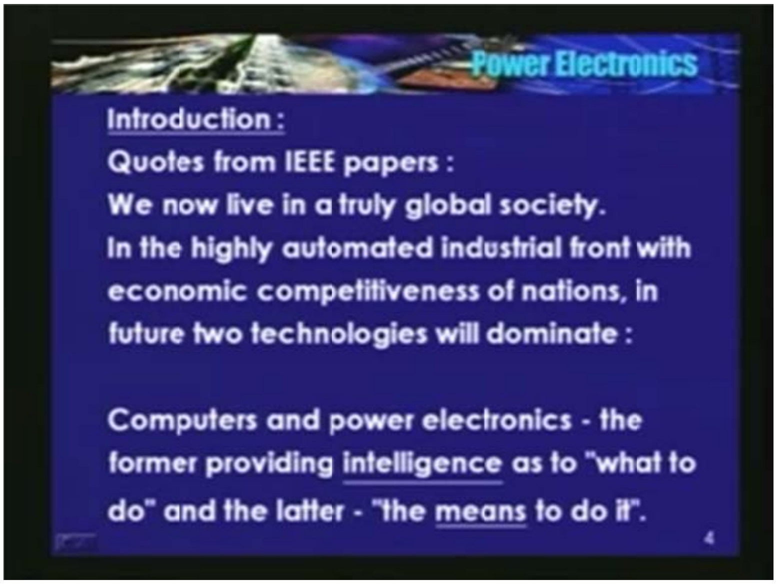

See, one of them is, we now live in truly a good global society, in the highly automated industrial front with economic competitiveness of nations, in future two technologies will dominate. What are they? One is computers and second one is power electronics. The former that is computers, providing intelligence as to, what to do and the latter, that the power electronics tells us the means to do it. Computers, they provide the intelligence and this is power electronics means to do it. So, power electronics is being compared with computers. These are two technologies that will dominate and all of us know, computers has become some sort of a house hold item, very important, being used everywhere and over the years, we have seen how popular they have become and how it has affected our life. At the end of the course, you will realize that the power electronics has also become or power electronic equipment have become some sort of a house hold item and is being used everywhere. So, that is the reason I told you that power electronics is a very important course. Very important and is very interesting and second quote I would like to give you, modern computers, communication and electronic systems get their life blood from power electronics.

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See the comparison. They get their life blood from power electronics. And third quote, again in IEEE paper, Solid state electronics brought in the first electronics revolution, whereas solid-state power electronics brought in the second electronics revolution. The various mile stones in power electronics, I will tell you some time later.

Now, let me tell you the energy scenario. Globally, 87% of total energy comes from the burning the fossil fuel. Fossil fuel is coal, oil and natural gas. 87% comes from burning of fossil fuel. Approximately, 6% comes from nuclear. So, they answer to 93% and remaining from renewables. Renewables means wind, solar, hydro. In our country, around 70% comes from coal. We have major thermal plants, 70% comes from thermal power plants. So all of us know, there is a limited fuel globally. See, it has been projected that natural uranium fuel is expected to last for 50 years or so. This figures, I got it from the literature, IEEE journals. So, natural uranium fuel is expected to last for 50 years. Oil is for approximately 100 years, natural gas for 150 years and coal for 200 years. See, this is the projection which is being reported as of now. So, the question that has been asked is that, will the wheels of civilization come to a halt at the end of 20 second century? Because coal is expected to last for 200 years or so. So, will the wheels of civilization will come to a halt at the end of 20 second century? I have no answer and let me tell you one thing, neither me nor you will listen, will be around to see the light of the day, whether these figures are true or false. But then, we owe one responsibility. We need to make a better place to live in, for the generation to come. We are answerable for the generation to come. So, we are bound to extend this period. How do we do this? One is use it very efficiently, use the electrical energy very efficiently. Second is improve the conversion efficiency. Use the electrical energy very efficiently or if there is a power conversion from one form to another form, say, AC to DC I want to convert, improve the efficiency of the converting equipment. Third is see whether the energy can be produced using renewables. Improve the percentage. So, three things we can do.

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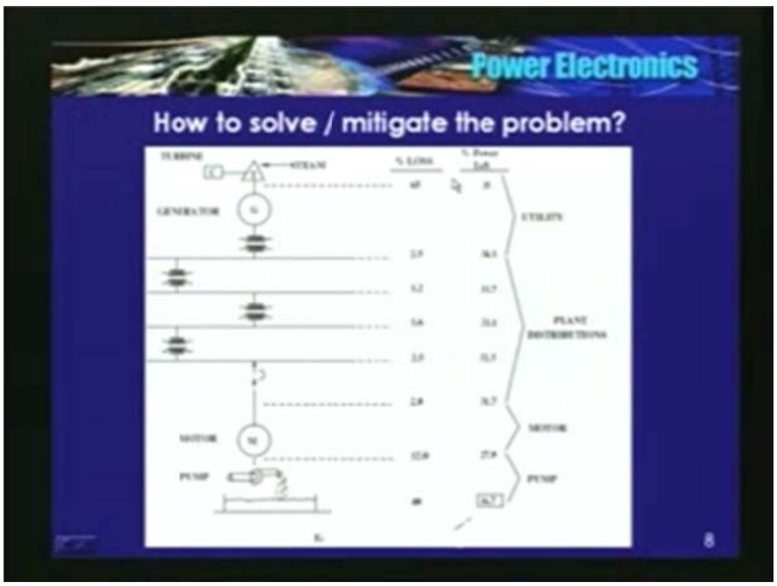

I will just show you a cycle that is used in power conversion. See, steam is the input, a turbine is driving a generator, the total loss here itself is of the order of 65%, major loss at the steam and turbine end. Again, this figure I got it from IEEE journal. Power is being produced, there is again, this is the various power transmission levels. So, generator is located at a remote end, consumed at, bulk of the consumption takes place in the urban areas. So, this is the power transmission and may be here is being utilized and these are the various percentage losses, there could be minor changes, that is okay. If you find here, only 16 point 7% power that is being left to you. 65% losses here and finally it travels here. It is just, 16 point 7% of power that is left.

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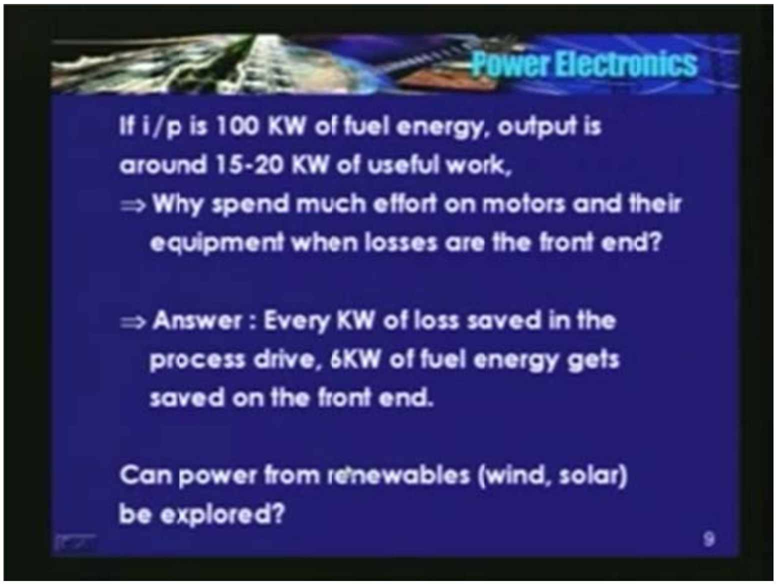

So, if the input is 100 kilo watt of fuel energy, if 100 kilo watt is the input, output is around just 15 to 20 kilo watts of useful work. I will repeat, 100 kilo watt is input of fuel energy. How much they will get? Output is, of the order of 15 to 20%. So the question is, why spent much efforts on motors and their equipment, when the losses are at the front end. Why to worry about conversion, improve the conversion efficiency of the equipment or the machines, when the bulk of the loss is at the front end or at the turbine end itself. See, answer is very simple. Every kilo watt of loss saved at the process end; see here, every kilo watts of power that is saved here results in saving of 6 kilowatts of fuel energy here, 6 kilo watts. 1 kilo watt here is equal to 6 kilo watt here.

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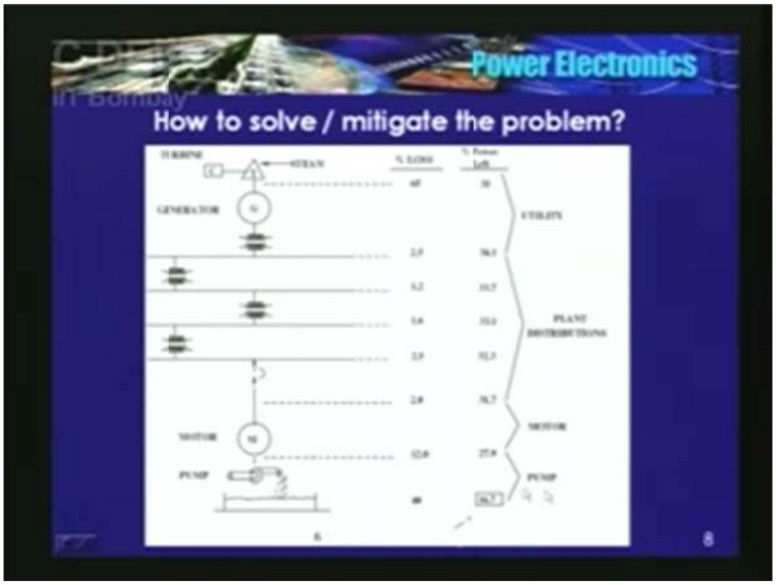

So, that is the reason I told you that, improve the efficiency, conversion efficiency. Second is use the electrical energy efficiently and if possible, try to explore more on renewable. What are the problems that are associated with the nuclear or thermal power plants or burning of fossil fuel? What is the problem? Nuclear power plant, waste handling is still a problem, safety of nuclear plants? What about burning of fossil fuel? They give out carbon dioxide, ozone, carbon monoxide, nitrogen dioxide NO_2. Coal burning, it give out the fly ash. Global warming, temperature is goes on increasing. Global warming, other day I read in one of the national dailies. It says that every year Mount Everest is losing its height at the rate of 10 centimeter. This was reported the other day in one of the national daily. Every year Mount Everest height decreases by 10 centimeters. That is because of global warming. That has resulted to climatic changes. It affects agriculture and vegetation. So in 1997, there was a conference at Quito, Japan. The developed countries, what they decided was to cut down the emission of gasses, a specific types. In other words, try to reduce the burning of fossil fuel. Try to reduce the urban pollution. Now, major concern in urban pollution is again IC engine vehicles. Can you do something about reducing the urban pollution? So, looks like there is a way or looks like there is a solution to all this problems. We all know, bulk of the power that is being consumed by electric motors. Bulk, and what are the majority of the loads? Major loads are induction motor, driving either a fan type of load or a pump type of load. Fan, pump, compressors. Bulk of the power that is being consumed globally is, induction machines driving either a fan types of loads, pump or compressor type of loads. And we know that induction motor, the speed is approximately constant for all practical purposes, all the machines that we have, separately excited DC machine, induction machine, almost constant speed. Speed does not change much and not a bulk power consumptions is by lighting. Lighting consumes another good percentage of power that has been produce globally. So, if you try to save on this power on lighting as well as power that is being consumed by motors if you try to reduce, that is going be significant reduction on this overall saving of the electric power. So, if I try to save 1 kilo watt of power at the load end, 6 kilo watt of approximately fuel can be saved at the input. I said bulk of the power is being consumed by induction motors and that are driving either fan pump or compressor. But, sort of torque speed characteristics of these loads. T_L the load torque is proportional to square of the speed. T_L is proportional to square of the speed. So look here, fan type of T_L is proportional to omega square. So, therefore power is proportional to omega cube.

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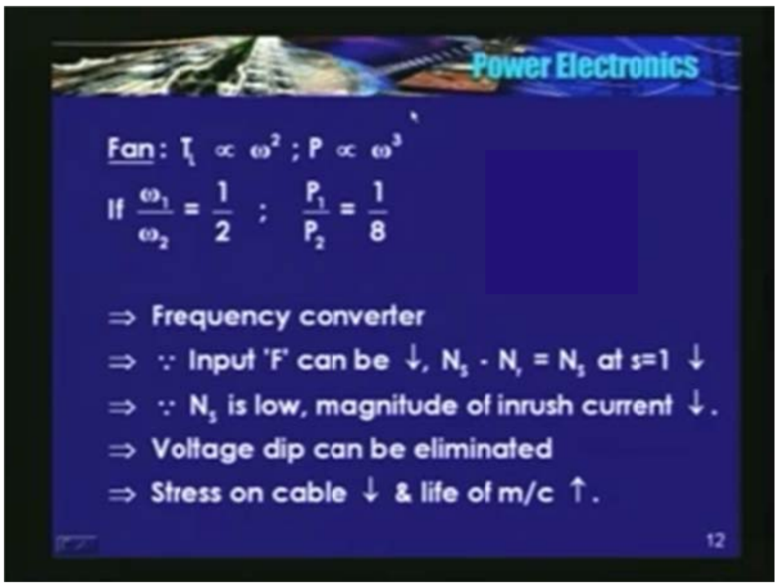

Now, if you want to reduce the discharge through the pump or you want to reduce the air delivered by the fans. I am not talking about the 60 watts fans, I am talking about high kilo watt fan that are used in a industry. If you want to reduce the air discharge, what will you do? Either you use dampers or in other words, dampers provide a resistance to the flow of air or use a throttling wall for the pump to reduce a discharge. So, by the using the dampers in the case of fans or using a throttling wall for the pumps, you may be able to reduce. Sorry, you will be able to reduce, the air supplied or the output of the pump discharge. The purpose is solved. You can reduce the pump discharge by throttling the wall, by providing the dampers, outlet dampers, you can regulate the air flow, at what cost? Power input, remains approximately constant. The drive, the motor taking approximately the same input, whether you have closed the throttle wall whether 30% or 50% or fully open, approximately the same. We are able to regulate the output. Instead, if we try to reduce the speed itself, speed of the rotation. We are able to regulate the air in the case of fan or we are able to regulate the discharge in the case of pump. Then what happens to the input then? See here.

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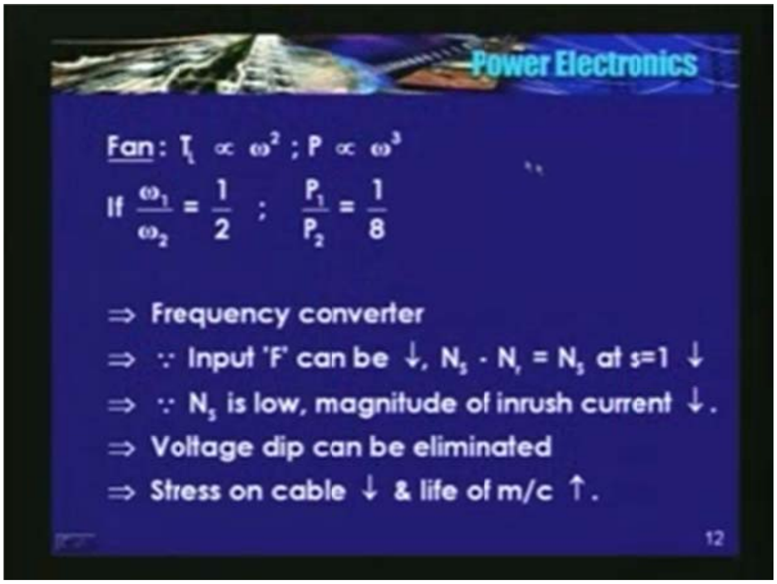

Power inputs, suppose the ratio of two speeds is point 5, omega 1 to omega 2, the ratio is 1 over 8. So, there is a significant reduction in the power that is being consumed, if you reduce the speed of rotation, one-eighth, significant reduction. So, you are trying to achieve both, same energy as well as regulate the output discharge depending upon the process requirement. But then again, at what cost? Nothing comes for free. I told you induction machine, almost for that matter, all the machines or for that separately excited DC machine, induction machine or constant speed motors, approximately constant speed motors. Here is a process, I want to change or regulate or vary the output discharge. So, in order to save the energy I want to vary the speed of rotation. Definitely, in the case of induction machine, we have to change the frequency of the input voltage, because induction motor runs approximately at the synchronous speed. So, if I want to reduce the speed of the rotor, how to reduce the synchronous speed itself? So, I require a frequency converter because voltage that has been supplied by the utilities is constant voltage, assumed to be constant voltage and frequency remains approximately constant. Variation is very small. So, constant voltage, constant frequency source, there is available. But then, I need to change the frequency as of now, because I want be change the speed of rotation. Now, what relationship that voltage and frequency will have, we will see some time later. So, as of now, we require a frequency converter to vary the speed, of the induction machine. So, using the frequency converter, I told you that we are able to save on electric energy. What are the other advantages? What happens the induction machine if I directly switch on to the supply voltage and supply rated frequency. So, 415 volts, 50 hertz, induction machine, what happens if I directly start it or DOL starting? It draws a large current, could be of the order of 6 as or rated. Now, that current has to come from a source, at force through the cable to the machine. So, there will be a voltage dip. That is why, in the sense, whenever you put on large hp motor, momentarily, the intensity of the bulk comes down, then the voltage dip. Second is a large current should flow through the cable. 6 times a rated current it can flow. So, a stress on the cable is also more if I directly start. That current is flowing through the machine winding. Stress on the machine winding also increases. In other words, life of the machine comes down, if I directly start it. What happens if I try to reduce the frequency itself? If the input frequency decreases, Ns minus Nr. Ns is the synchronous speed, 120 F by P minus Nr. Nr is the speed of the rotor. So, Ns minus Nr is nothing but SNS. S is slip, slide me hai na and at starting, slip is equal to 1. So, Ns minus Nr is equal to Ns itself during starting. Now, if I reduce the frequency, Ns has come down.

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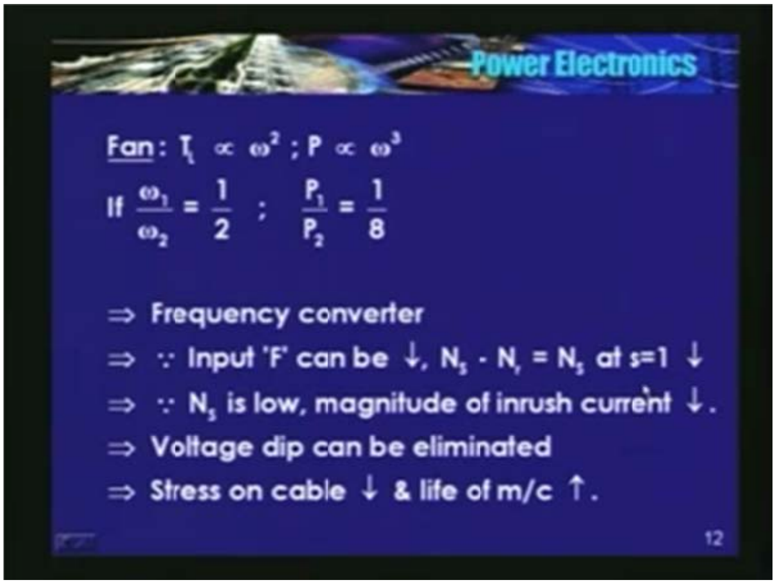

I told you, as of now, I am just talking about reducing the frequency. While reducing the frequency, I have to reduce a voltage also. Reasons, sometime later I will tell you. As of now, I just said a frequency converter. It has to vary the frequency of the output. So, what is the relationship what between the frequency and output voltage, we will see some time later. So, if I am trying to reduce, if the output frequency can be reduced, Ns comes down. It so happens that as I reduce a frequency, I have to reduce applied voltage also. So, magnitude of inrush current comes down. So, if the magnitude of inrush comes down, the voltage dip gets eliminated, stress on the cable reduces and improves the life of machines. So, looks like, there are lot of benefits. One is unable to save the power, second is, voltage dip gets eliminated, stress on the cable gets eliminated, reduces rather, life of the machine improves. So, what next? What happens in the machine is being fed by a constant voltage and frequency supply? Say 415, 50 hertz is running stably, delivering some load torque. Input voltage is 415, rated voltage that has been applied. So, b is constant. If b is constant, flux in the machine, is constant and it is the rated flux because am applying the rated voltage at rated frequency.

So, area flux is the rated flux. Therefore, the constant losses also remain constant. The core losses, core losses remain constant, because flux is constant. Assume that load of the motor is varying. In other words, motor is supplying a variable torque. If the load of the machine is varying, that is a process requirement. Assume that it is changing, the variable losses which are function of load, they also keep changing. You have kept the input voltage constant. Therefore, area flux remains constant, core losses remain constant. Load is varying, so variable losses also vary. Now what are the conditions for maximal efficiency? Condition for maximal efficiency is constant losses should be equal to variable losses. As of now, am neglecting the frictional and wind age. So, if I am feeding a motor, directly from utility supply, wherein input voltage is assumed to remain constant and if the load of the motor is of variable type, when the machine is lightly loaded, efficiency of the motor is very poor. So, it is possible to improve the efficiency of the motor when it is lightly loaded by decreasing the flux. See, condition for maxima efficiency is variable loss should be equal to constant losses. When the load on the motor is varying, motor is lightly loaded, variable losses have come down, constant losses have remained same or core losses are remained same. Now, I want to reduce the core losses. I can reduce the core losses by reducing the air gap flux density. That I can do by reducing the input voltage to the motor. How do I vary the input voltage to the motor? In the lab, maybe there is an auto transformer. The size of the auto transformer could be as big as the size of the machine itself. So definitely, it is bulky, entire, overall set of motor as well as auto transformer, plus it is expensive.

By the way, how are we varying the speed of the fan? We are using a regulator to regulate the speed of the fan. What exactly are we doing? We are applying the reduced voltage to the motor, in order to reduce the speed. See here, here are two regulators.

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This is a old one, very rugged. Variation is in steps. If I keep it in very low speed, after sometime this regulator becomes very hot, extremely hot. That is the reason we have to mount it on the switch board and there are lot of openings here for the air to flow, so that to cool the entire set up. There got a resistance inside. To cool this regulator, these are the openings and it becomes very hot when the speed of the motor is very low. In other words, when you introduce the resistance in the circuit, it becomes hot. Very raged, may be.

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See, here is another regulator. You could have seen a small elegant regulator. I can have a very smooth control, very smoothly varying speed. Here, just see, steps, it is a contacted type. Here, very smooth, both of them doing the same function, regulate the speed of the fan. It is mounted inside the switchboard. You can see just the knob, smooth control. So, if it is so small mounted inside the switchboard, definitely, heat dissipation is negligible. If there is a heat dissipation, if it gets hot, definitely we have to mount it outside. So heat dissipation is very low, very elegant. How is this possible, from such of massive regulator, heavy regulator to, such a small elegant regulator? May be this question, I will answer sometime later.

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So, here is an internal structure of the regulator. May be a coil, a capacitor. Here is a power semi conducted device. I told you suppose, it is a heart of a power electronic equipment. This is one type of a power electronic device, power semi conducted device, this is the one, L, C and small small resistors, high voltage resistor. This is a power semi conducted device …… So, this is being used in our home, very elegant, light weight, very small, no heat dissipation, conversion efficiencies should be very high because there is no heat dissipation. Heavy, step variation in speed, dissipates power, so definitely, power consumption is high. Overall conversion efficiency is low. So, this is another example.

So, coming back to the theory, if I can try to reduce the input voltage to the motor, which is driving a load of variable load, it is possible to improve the efficiency of the machine. So, we can have eta is equal to eta max, of maximal efficiency even at lighted loaded conditions. How to do this? Who will address this problem? What is third benefit? See, I was told that in Japan 70 % of the air conditioners, the speed itself is varying. Speed of the motor itself is varying. In other words, frequency has been changed, in 70% of the air conditioners used in Japan. They use variable speed drives. Whereas, instead of that thing just not heard, may be in the US. Why? May be energy, cost per unit may be very low in the US. Japan, it must be very expensive. Looks like, everything has been driven by economics. What is the use of using a variable speed in air conditioners? Or to understand that what happens in the window air conditioners that are been directly switched on or off. There is thermostat inside. Temperature is being controlled within a band, hysteresis band. When the temperature falls below a certain value, AC is put off, temperature starts increasing and when it crosses upper limit, AC is again switched on. What is a problem here? Same problems, direct online starting of induction machine, voltage dip, voltage cable wire or stress on the cable and machine life comes down. Instead, can you vary the speed itself, slowly accelerated, so you can now, you can control the temperature, very smoothly. Very smooth, control of temperature is possible, air conditioners as well as refrigerators.

What next? slip ring induction machine. When do you go for slip ring induction machine? When the power rating is high. For low power motors it is invariably, squirrel cage is the constructions, cage rotor. As the power rating increases, slip ring induction motors can be used. So, in any induction machines, s times the air gap power input is dissipated as heat in the rotor. So, air gap power input is approximately equal to input power itself. So, s times the input power is dissipated as heat. Now, instead of dissipating as heat, can this power be fed back to the source? Yes. Can I recover? What are the power that is there in the power that has been dissipated as heats? Can it be fed back to the source or is it possible to increase the starting torque and decrease the starting current electronically? Yes, our machines teacher has told, connect a resistor r to the slip rings, whereby, reducing the starting current and increasing the starting torque. Can you do this electronically? See, I am posing various problems to you and at the end. We will see, whether this problems can be addressed using power electronics. More on this, we will see in the next class.

Thank you.