Course Name: Design of Electric Motors

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Title: Realization of Electrical Machines-2

Greetings to all, in the last lecture we have discussed the realization of a DC machine from the basic principles of a magnetic fields. In this lecture, we will discuss how to realize the other machines from the basic principles of a magnetic field. So, if you will see here, the DC motor is in this manner, one side field winding is there, other side rotating armature is there, through brushes we are giving the DC supply, but it is a type of AC machine. Now, instead of giving through brushes and commutators, can we avoid it? Can we give the AC directly and can we realize some type of machine? For that, we will swap the stator to rotor side and rotor to stator side. This field poles will push it to rotor side that is the moving object now and stator thing, this is the stator thing that we will push it outside that will be stationary now. We can see this one.

Earlier in a DC machine, we are giving AC to this armature. Now that armature, we are visualizing as a stator side that is stationary object and we are feeding AC directly, no need of any brushes and commutators with respect to this structure stator structure. Now, at the rotor side, we have a field poles because the swapping of stator to rotor side and rotor to stator side is done. To feed the rotor or to excite the rotor windings, we require the brushes because the rotor requires only DC supply, field poles and stator side, we have the variable fields because of the AC excitation.

Rotor supply we are giving through brushes. We are able to eliminate here commutators, but brushes are required to make the excitation for the rotating object or rotating field poles at the rotor side that is this one. So, stator side AC supply we are giving and it will generate the variable fields and rotor side DC supply with constant field poles are there. Based on the attractions and repulsions of these two things, it will work. This motor is called as a synchronous motor.

Why synchronous motor is there means like name is there is a locking like at the stator side. Let us consider north pole is there and this is a one pole pair. This side south and north in this manner, we are able to generate it at the stator side. Rotor side north and

south is there. Then based on the repulsion, it will rotate and the next situation it will happen here south and here north at the rotor side and stator side we have south north this side and north south this side because magnetic fields are dipoles.

Here magnetic locking is there. If stator magnetic fields are rotating, these fields are rotating. Let us assume it because magnetic locking is there. Then we have considered that how to break that magnetic locking to rotate the rotor. If we will consider rotor also rotating, but stator side the mechanical structure is not rotating.

Only magnetic fields are rotating and rotor is rotating along with the magnetic fields at the stator side. Once the magnetic locking is happened, here magnetic locking is happened. Along with the stator fields, the rotor also rotating with this magnetic locking principles because of this reason, this machine we will call it as a synchronous motor or synchronous machine. Here the torque depends upon the mutual terms because both sides we have excitations. The reluctance terms because of the magnetic locking, the reluctance terms will become 0.

There is no variation in the reluctance. dL 1 by d theta and dL 2 by d theta is not changing or I can say reluctance based force is not generating in this particular machine because of that reason we will see only mutual torque. The torque with respect to the reluctance terms will equal to 0. In the other words, we can say the self inductance with respect to the stator side and self inductance with respect to the rotor side is not varying with respect to the angular displacement of a rotor because of that reason these two terms are 0. Now, the brushes are required in this particular machine to get the excitation for the rotor, but how to remove these brushes again? For that do the same thing, but instead of swapping stator and rotor stator side, you assume that variable field poles we are creating with respect to the AC supply.

The stator side same structure is there similar to the DC motor. Assume that we are shorting the coils instead of connecting through brushes and commutators to the DC supply, we are shorting it. One side we have the variable flux. Here flux is varying with respect to the AC supply and one side closed coil is there. What will happen based upon the Faraday's law? There is an induced current in a closed coil.

This is the magnet and other side we have a closed coil. Then if you bring the magnetic fields towards the coil, then automatically a current will induce in this particular coil based upon the Faraday's law. This induced current will produce the magnetic fields that is in this manner. Consider only one conductor is there, current carrying conductor here this side dot and this side cross. Then based upon the thumb rule, we can find the magnetic fields directions here and even though multiple conductors are there at the rotor side, I am considering one conductor for simplified example.

The north pole will form this side and south pole will form this side. Based upon the attractions and repulsions of these two fields, one field at the stator side and one field at the rotor side, based upon the attractions and repulsions it will work. We have seen the DC mission and we have seen the synchronous mission and now induction mission. These missions are working based upon the same principle that is attractions and repulsions of two magnetic fields. Here the torque is mutual torque again.

There is no reluctance torque terms dL 1 by d theta L 11 dL 22 by d theta terms are equals to 0. There is no variation in inductance with respect to the rotor position and the reluctance term is equals to 0. Only mutual torque with respect to the current I 1 and current I 2, I 1 is with respect to the stator side and I 2 is with respect to the rotor side. Based upon these two currents or based upon the resultant fluxes or magnetic fields, we will see a torque mutual interaction between these two things. Here we solved the brushes and commutator problems.

There is no requirement of brushes, there is no requirement of commutators in this particular mission. Now, we will see how to avoid the brushes and commutators in a other manner in a different solutions. Consider the study 3, stator side we have the excitations, rotor side is a permanent magnet. The brushes and commutators requirement is there because of the excitations at the rotor right, windings at the rotor. If you have a windings at the rotor side, then only we require the brushes and commutators right to give the power.

If you will consider the permanent magnet here, there is no requirement of brushes and commutators. Consider stator is this one and rotor is permanent magnet and stator is excited with variable supply that means, we can change the poles at the stator side. Here this is set one pole pair at the stator side, then here the magnetic locking is there again how to avoid this magnetic locking. Bring one more coil here like or one more pole pair. Based upon the attractions and repulsion it will work right.

The rotor will move in this fashion, the rotor is rotating in this manner based upon the attractions and repulsions of the magnets. Now, what it will happen again magnetic locking is existed between the north and south pole here. This is north and this is south, there is a magnetic locking. To get the rotation next, then we will excite the stator pole set one and again set two like this manner, we can excite the coil one and coil two at the stator side, then we can get the continuous rotation. We will see the currents here, this is the current with respect to the pole pair two and this is current with respect to the pole pair one.

If we will excite properly, then we can see the rotation at the rotor side. This type of machine we will call it as a BLDC motor. We have one field pole pair at the stator side and based upon the attraction and repulsion, the rotor will rotate and in order to get the

smoother rotation, we kept the second coil set also. If we will excite coil one, the rotor will try to align with respect to the coil one. If we will excite the coil two, rotor will try to align with respect to the coil two.

Based upon the attractions and repulsions, it is working. That motor is called as a BLDC motor. Now, if we will replace the stator side concentrated field poles or concentrated winding kind of structure with distributed conductors and if we will give the AC supply, then that motor is called as a BL brushless AC motor. The BLDC motor is also an AC motor, but from DC to AC, we are doing here the conversion by utilizing the power converter. These coils require the variable supply only like this manner.

Here we can see the red color waveform also AC and blue color waveform also AC. The operation with respect to the BLDC motor is an AC machine, but because of the converter arrangement and outside DC supply, we will name it as a brushless DC motor. There are no brushes. That is why the name it call it as a brushless DC motor. Instead of DC and concentrated windings, we will utilize the AC supply directly and we can utilize the distributed windings.

That motor is called as a brushless AC motor and also call it as a permanent magnet synchronous motor. Here the torque is nothing, but a mutual interaction of magnetic flux as well as the stator flux. One side we have the current, other side we have the flux linkages or flux with respect to the permanent magnet. Interaction of these two will give the torque in this particular machines. If we will consider the study one where there is no magnets, there is no brushes, there is no commutators, how to avoid the brushes? That is what our objective is.

In that particular case, we will utilize the study one. Rotor side we have the soft iron. Based upon the applied field at the stator side, rotor will try to align towards the magnetic field. We can see here in this particular case, we are exciting the stator pole pair one or pole side one. Then rotor is aligned towards the applied magnetic field.

The induced poles here, this is south and this is north. Next iron piece is attracted towards the magnet. Next in order to make the rotation, we have to use the one more coil that is this one. Now if you will excite this coil, rotor will move in this manner or iron piece will try to align towards this set two and assume there is no set one. We are removing the excitation for set one and we are exciting the set two.

Then rotor is aligned in this manner. We can see that one. Rotor is rotating in a clockwise manner and it is aligned with that excited coil. This particular machine, we will call it as a switched reluctance machine. This machine works based upon the reluctance principles.

The category with respect to the reluctance principle working machines are SRM motor, synchronous reluctance machine where the stator structure is distributed winding and rotor is a iron piece. Stepper motors also works upon the variable reluctance principles, but some hybrid motors also came to make the smaller step rotation. But in a conventional stepper motor with larger size of the poles and lesser number of teeth, then the stepper motor also works on the variable reluctance principle and there is no magnets. Torque is only reluctance torque in this particular case. This is the realization of electrical machines with respect to the basic principles of magnetic fields.

We will see exactly what type of windings, arrangement and what kind of machine structures are available with respect to the existing machines. We have concluded as of now, any rotating machine requires two fields to generate a torque based upon the attractions and repulsions. It will work. This is the conclusion from this last lecture as well as in this lecture. Based upon the attractions and repulsions of the two fields, it is generating a torque.

Now, what kind of windings we require? Generally windings require to generate these two fields. If a permanent magnet is there, then there is no need of windings, but if electromagnet is there to generate these two fields, we require the windings. Winding is an arrangement or a group of conductors to create the magnetic fields. First, we will see the winding structures and arrangements for the DC motors.

That we can see here. This is the DC machine concentrated winding at this particular point, stator side, those are the field poles and distributed windings at the rotor side with the armature. This is the armature structure. It is rotating one and these are the commentators and brushes arrangement will be there separately. The stator side field winding is there that is generating field one. Rotor side armature winding is there that is generating field two.

The interaction of these two fields will result the torque. The application of DC machines, the principle is same with respect to the DC series motor and shunt motor or any type of motor. The interaction of these two fields will generate a torque. In a DC series motor, what are the applications we can see here? We are utilizing in cranes, air compressors, lifts, elevators, etcetera. Similarly, DC motor, DC shunt motor applications, permanent magnet DC motor applications and compound motor applications also we can see in this slide.

We are mainly utilizing in conveyors, elevators, compressors, rolling mills and centrifugal pumps, blowers, etcetera, fans also. Now, we will see the machine with respect to the permanent magnets, no brushes and no commutators. Just replace the field windings here.

This is the one. This is the field winding side. There are magnets. They are electromagnets and are replaced with permanent magnets and here windings at the rotor side. This is the stator field concentrated winding and rotor magnetic thing. There is no requirement of brushes.

Similarly, here also inner rotor and outer stator. Here inner stator, this side, inner stator and outer rotor. Both types require the two fields. The interaction of these two fields will result in the torque. One field is coming with respect to the electromagnet at the stator side and one field is coming with respect to the permanent magnets.

These are the brushless DC machines. The applications will be same as the DC machines in the low power applications like laptops and other places also. We are utilizing the BLDC machines now and even ceiling fans also we can see. These are the few applications with respect to the brushless DC machines. Now, I will show the exact practical machines, how the distributed winding and concentrated windings will exist in the machines. We can see here, this is the distributed type of a winding.

You can see in the core, this is the distributed winding and this is the concentrated winding. We can consider these are the field poles, concentrated windings and it is a distributed winding. Number of slots are high, more number of slots are there and more coils we placed in the stator structure and this is the rotor structure for induction motor. Whenever we are discussing the induction motor, I will show you this thing. This is the squirrel cage rotor, distributed winding, concentrated winding and some squirrel cage type of rotors we can see here.

For the synchronous motors, the stator side we have the distributed winding. That is what I have shown now. Distributed winding at the stator side that is this one and the concentrated winding at the rotor side like this kind of structure. It is not for the synchronous motor, but the example for the concentrated winding I am showing in this image or in this machine. So, coming back to the PPT here, we can see the stator side winding and rotor side windings.

Based upon the attractions and repulsions of the fields created by these two windings, it will work. Permanent magnet, synchronous motor, the rotor side we have the permanent magnets and stator side it is normal, distributed winding same as this one. The applications of the permanent magnets we can see in this slide. We are utilizing in machine tools, motor generator sites, electric vehicles and timing devices and belt driven reciprocating compressors and lifts, rolling mills, cement mills etcetera and power factor correction devices and renewable energy systems. Most of the places we are utilizing the permanent magnet synchronous motor also.

Induction motor we can see here that is this one only. Exactly induction motor is this is the one what I am showing. Stator side distributed winding and rotor side squirrel cage.

There is no winding, closed coils or shorted coils at the rotor side and distributed winding at the stator side. So, these two things like with respect to the distributed winding and AC supply, we are getting the variable fields or rotating magnetic fields we are getting at the stator side. At the rotor side, these variable fields will induce the currents in the closed coils.

This induced currents will produce the magnetic fields at the rotor side also. The interaction of these two fields, stator side fields and rotor side fields will generate a torque that is the principle of induction motor or mutual induction principle also same. The applications of the induction motor we can see here. We are utilizing in fans, electric vehicles and paper industry and water pumping applications and roller tables, cranes, most of the applications we are utilizing the induction motors also. It is the driving force and greater than 70 percent to 80 percent we are utilizing the induction motors only.

One type is the squirrel cage, other type is the slip ring induction motor where the coils are closed coils are there copper windings. Here the shorted copper bars are aluminum bars, but here copper windings are there that is slip ring induction motor. This is squirrel cage induction motor. There are two types are available those two things, but principle is same based on the mutual induction principle it is working. Next switched reluctance machine, stator side we have the concentrated binding which will generate the field one and rotor side just simple iron piece is there.

Just if we will electromagnet is there and we are placing the iron piece near to that then automatically the iron piece will attracted towards the electromagnet that is the principle of switched reluctance machine based upon the variable reluctance it is working. And synchronous reluctance machine is same, but the stator side the distributed winding is there. Rotor side simple iron piece based on the reluctance it is working. Applications we are mainly seeing in electric vehicles two wheelers and other places at present we are not prototypes are not available with respect to the electric vehicles. In future we will see the switched reluctance machine based vehicles also.

But in other places where we are utilizing the switched reluctance machines we can see here coil winding as well as unwinding equipments general machine machinery like pumps and fans etcetera and lifting machines and manufacturing equipments and etcetera. These are the few applications with respect to switched reluctance machine. Next variable type variable reluctance type of motor is stepper motor. Here we can see stator side is a concentrated winding and rotor side we have the soft iron or some magnet based.

It is a hybrid motor to get the small steppings. If you want larger step value or lesser number of poles then we can go with the soft iron piece also. In a stepper motor we want a like smaller angular rotation small step change for that reason we have the

permanent magnet on top of that iron piece with small steppings that is what we can see in this image. Whenever the opposite poles will come into the picture then the attraction will happen and the same poles will repel each other. If the number depends upon the number of teeths at the rotor side the angle of rotation will matters in a stepper motors. The application of stepper motors we can see in a robotics digital watches and printers x y plotters and motion control systems.

And these are the different machines which are existed in the literature DC machines, AC machines and other type of machines. All machines working on the same principle the attractions and repulsions of the magnetic poles. How we are creating this magnetic fields will differentiate from one particular motor to other particular motor. In the synchronous motors if let us say permanent magnets are there then one side permanent magnets other side electromagnets. So, only the creation of magnetic fields will differ in one motor to other motor, but the working principle is same as the attractions and repulsions.

These are the different machines, bound field permanent magnet machines and synchronous machines, asynchronous machines that is induction motors and reluctance machines and universal machines where it will take the DC as well as AC and servo motors and vernier permanent magnet and hybrid permanent magnet just a slight variation with respect to the designs and electrostatic motors and static machines like transformers. These are the different type of existing machines. With this I am concluding the this lecture. In this lecture we have discussed the realization of electrical machines and winding structures with respect to the different machines. Thank you.