Electrical Machines - II

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Lecture – 06
Analysis of Single Conductor Generator and Motor

Welcome and we have started our discussions on fundamentals of motoring and generating principle of operations and everything actually depends on Fleming’s left hand and right hand rule. So, for doing that I was taking one example, a single conductor moving in a magnetic field is the one I was doing and I do this diagram which was really clumsy, but in any case it was correct if you see this one.

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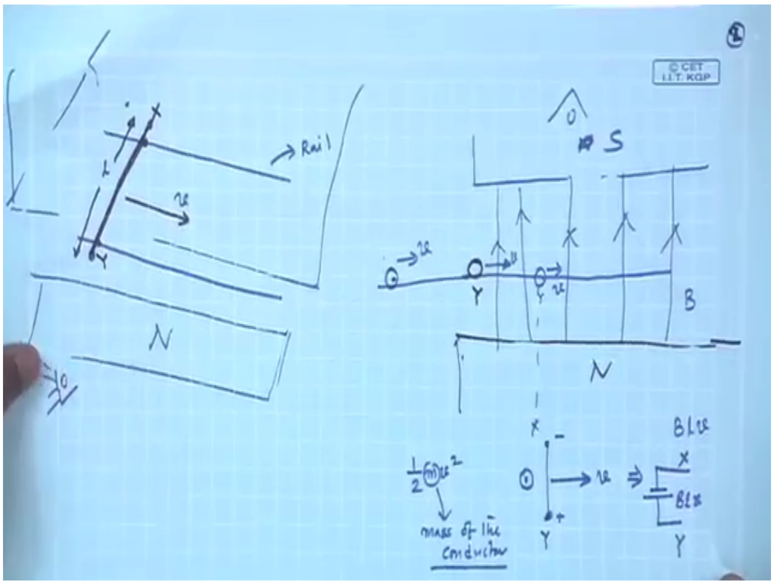

But today one of my colleagues helped me to draw this diagram in this fashion professor Chatterjee and this I will be showing to you this is what I was trying to describe the situation.

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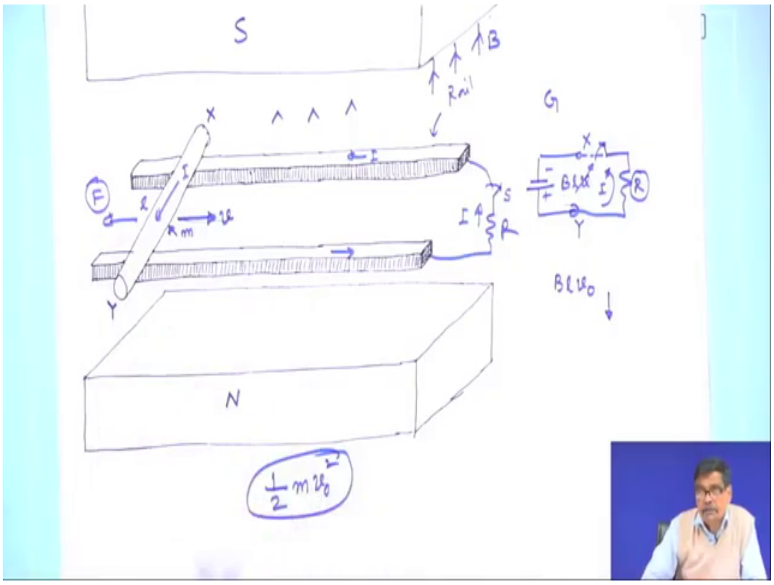

For example, this diagram what I meant to say, this is my Y, this end and this end is my X and what I was telling this is a south pole and it extends up to infinity, infinitely long, these 2 are rails, these 2 are rails this and this pair rails this is the conductor say copper conductor it is on a will and it can travel along this track.

Now, if this moves, so with a velocity V then I was telling and this is north pole. Therefore, lines of forces will be going this way, all along the track all along the blade it will move to B. Therefore, and if the length of the conductor is l, this length a length X Y and if it moves then it will have induced voltage and the induced voltage you can find out by applying right hand rule, north to south with your middle finger this is the velocity these 2 are inputs and this is Y will become plus, x will become minus, so it will become sort of battery like this between Y and X here.

And the magnitude of these voltage is B l v plus minus ok. Similarly, you could pass some current and this rail is also got good conductor of electricity. So, in the next arrangement what I have done is this.

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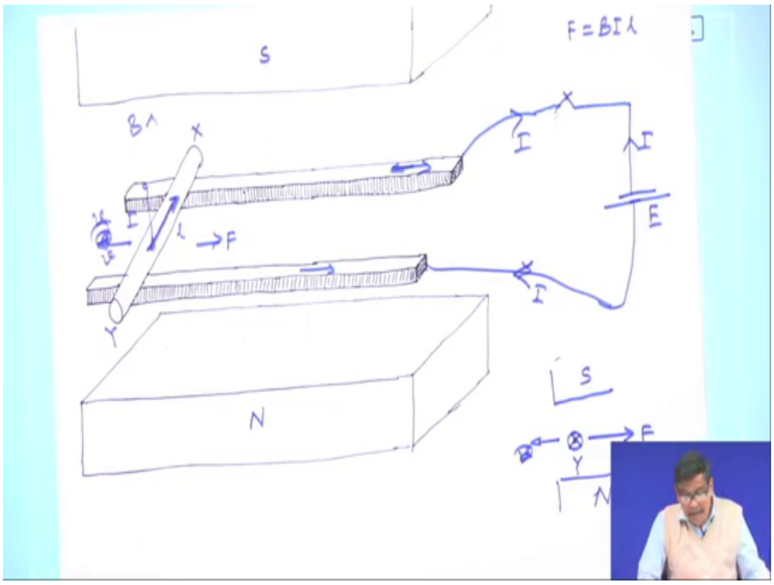

Here this is the conductor, it is suppose resting on the dells, here is once again say south north let us not disturb. Then what you do? You take some flexible wire and connect a switch here and connect some battery. If you close this switch current will start flowing, let it flow like this, I it will flow like this and return path will be like this I, I.

Now, this conductor which is resting, you have switched on the current is I and it has got a length l then it will experience a force. What will be the magnitude of the force? BIl is the magnitude of the force. Incidentally this b l direction of l and I are same, they are mutually perpendicular. So, magnitude of the force will be this is the direction of the B, this is current. So, it will start moving in this direction, is it B B I l. It will start moving in this direction B I; it will start moving in the opposite direction like this.

And this diagram what I was telling is can be done if you look from this end, from this end from front side it will look like there is a south pole here, there is a north pole here and you will see only the Y end side of the conductor, that is Y, X is behind and it is carrying a current towards Y, so, it should be dot.

So, direction of the force I can find out by applying left hand rule; that is B fore finger, I this way and velocity will be like this. What I will do to and it will move in this way. If I reverse the polarity of the current, suppose this I make then this will become cross, then this will be the current direction I, this will be the current direction and then the conductor will start moving in this direction, experience a force in this direction. But anyway this now gives you a clear understanding of the system we are talking about.

With respect to this, so it is a single conductor, it can generate voltage between its 2 ends and it can experience also some force when it is moving; that is the thing.

Now, the interesting part of it is suppose you have connected the polarity in this way, current is flowing like this is B, so B I and it will start moving in this direction, it will experience a force, I think this picture is now clear. This is B, this is I, B is this way, this is I and this is the force to move. But the point is the moment it starts moving a very interesting thing happens; what is that interesting thing?

Earlier when it was stationary current in the circuit was v divided by y r whatever is the R, but the moment it starts moving we just learned that a conductor in motion and placed in a magnetic field must have a generated voltage across X and Y between these 2 points and the value of this voltage is B l V. Therefore, current in the circuit now is decided no longer by E alone is there, but between Y and X it becomes a seat of EMF.

These 2 EMF's divided by resultant of these 2 EMF's divided by the resistance of the path should decide the current. Therefore, people say both motoring and generating action goes side by side. Similarly you see these are very interesting thing, a conductor moving in a magnetic field, it has generated some voltage B l v with the polarity marked as shown it is generator operational it is moving.

Now, why do we generate voltage? If you generate a voltage and keep it open circuited how does it help you? It must connect some load across it. Suppose the load I will connect across this with a switch I will connect a load. I want to use this power suppose it is a heater.

So, a voltage has been generated like this between Y and X and so it is opened and therefore, no current is flowing only voltage induced is B l v open circuit voltage if you connect a voltmeter between these 2 points, it will read that, but I want to utilize this power suppose it is a heater, so I will close the switch.

The moment you close this switch current will move this way, is not and then I soon discover o there is a conductor it is carrying a current I in this direction and it is placed in a magnetic field. Therefore, it must experience now a force and the magnitude of the force is BIl and it will be in which direction? This is I, this is B and the force experienced you apply your left hand rule will be in the opposite direction of motion; got the point? Therefore, when the generator action is taking place and you want to utilize that power in some circuit elsewhere, you soon discover that the conductor now experiences a force in the opposite direction.

Now, let me repeat once again. S was opened, there was a voltage between these 2 point generated and let us assume the track has having no friction, no air friction ideally no friction is present. Therefore, this conductor was moving with a constant velocity v and for that I do not require any force to be applied; that is what Newton's law tells us to move a thing with a constant velocity you do not require any force, in a frictionless environment ok..

So, everything was fine it was moving with a velocity V that is in other words what I am telling no one is pushing this conductor. Conductor is moving on its own with constant velocity v over a frictionless path, no friction nothing. And it can go on moving like this, provided this magnet exists infinitely long along the crack length everything is fine, but the moment you close the switch I say that this conductor has to carry. Now, current because it has already become a seat of e m f equivalent circuit in the electrical mode is like this.

So, there is an I and the moment this I flows now there appears a force in which direction? In the opposite direction of motion this force with S closed. Therefore, what will happen? This fellow must decelerate no friction is present. It was initially moving with a velocity v, now you want to utilize this power here, convert that mechanical power to here and the moment you do that there appears an opposing force against the direction of the motion of the conductor.

Therefore conductor must decelerate opposing force its velocity will decrease, but nonetheless its velocity will decrease, but whatever be the velocity that voltage B l v will be there. Of course, it will no longer now be a constant voltage because velocity is changing, it is decelerating. It will go on decelerating velocity suppose initially velocity was 10 meter per second, it will become 8 meter per second, 6 meter per second so on.

Progressively velocity will decrease. Finally, what will be the fate of this motion? Finally, it will come to a stop, because no one was helping the conductor to push along. Initially it was given some initial velocity, suppose the initial velocity was v naught then after closing the switch I find v naught decreases progressively and finally, it becomes 0 and the game will be over.

Now, the question is who what is the amount of energy which will be dissipated in R? The amount of energy which you can have has to come from the stored energy of this bar, it is mass is m and its initial velocity was v naught, suppose just before closing the switch velocity was v naught this was the energy stored and if you calculate I square RDT if you integrate it will has to become this one.

Therefore, you see in the generator mode of operation also when you want to extract power out of the generator, the kinetic energy stored in the conductor decreases that energy is being converted to electrical energy and in R it will be dissipated. But it is not a good arrangement, after all you can see after some time velocity will become 0. That is why if you want to have a sustained generator operation then what I should do? Someone must be ready here the moment you want to extract power from the generator opposing force comes.

But somebody else externally must also apply that same opposing force to the right so that velocity remains same and magnitude of the voltage generated remain same. I have to make such an arrangement then only it will be generating power. So, somebody some prime mover or somebody must push it along the direction of V so that velocity remains at v naught all the time and your generator functions.

And this is how you to get power electrical power mechanically you have to do some work that is why that forward force is to be applied and that is called a prime mover in a rotating machine. You load the machine then your mechanical supporting system must react to that and exert pressure force or torque so that velocity is retained.

Otherwise without any prime mover connected, the game will be over soon, will be not whatever kinetic energy that will be dissipated. Therefore, in generator mode of operation, there must be a some prime mover, some external agency it should be ready the moment you extract power that fellow should push it. So, that velocity remains same, so that voltage remains same and you get power all the time across R that is the whole idea we will come to this much more.

Now, all this things I till now told rather in language, now let us try to understand what it will go on. So, henceforth I will draw it like this.

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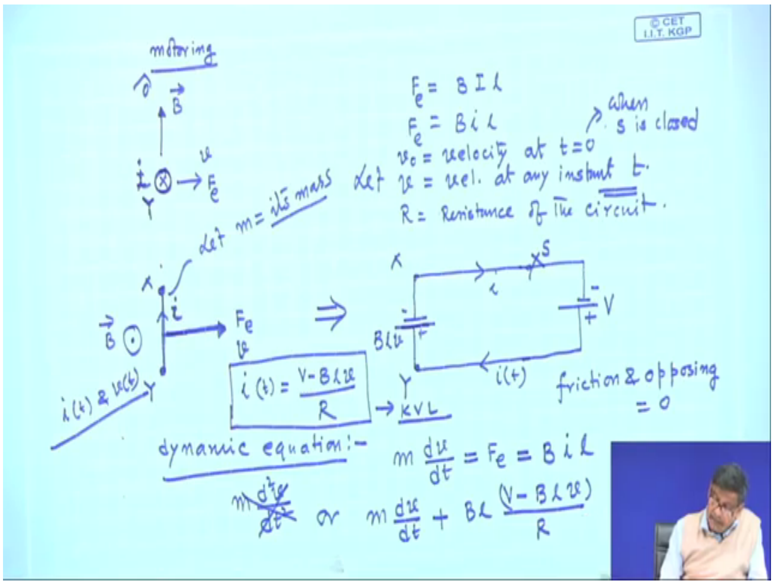

Say this is the conductor a sectional view sectional view, looking from this end your I is here this diagram I will draw. So, this is the conductor, it is suppose a conductor is there and this conductor is perpendicular to the paper and there is a magnetic field B. This elaborate diagram, I will now replace by this simple one if you have understood this. So, this is B and this end is the end Y of the conductor, the other end is X, which I cannot see because from this end I am looking and, but I am certain I can connect a battery also for example, this one this diagram I am doing.

So, I will connect a battery such that through the Y current will enter and through this section current will leave. Is not? So, this is cross, it is carrying a current I, motoring operation. Now if this is the theme, then the force experienced by the conductor will be B, magnitude of B, magnitude of I and magnitude of l. And let us write a small letter i, because we will soon see this I has to become a function of time. Suppose, at any instant this current is i, so Bil is the force; so, in which direction the conductor will start moving? If this is B, this is i into the paper conductor will experience a force F and this force is called electromagnetic force because of the introduction of B and i F E will be there.

So, it will start moving along this direction. Therefore, the direction in which the conductor will start moving is decided by the direction of F e, F e is the electromagnetic force, it will start moving. But as I told you the moment it starts moving, it will have some induced voltage in it. Therefore, this circuit if you look from the top, it looks like this way. This is the end Y, this is the end X and it is experiencing a force like this, it is moving with a velocity v in this direction, it has started moving and the current direction is like this, i small i am writing why you will immediately know no point in writing i. So, this is the direction of force and what is B? B is from this coming out.

So, you see Bil this is the force. But now I say suppose conductor has started moving at any time t, let v is equal to velocity at any instant t, what is t equal to 0? t equal to 0 is the instance when I have closed the switch, this is s t equal to 0. I have energized this conductor and rails I am not drawing it is going like this B i l is the force.

Now, the question is did this one this conductor between X and Y, it is moving now with a velocity v and placed in a magnetic field. Therefore, it will become a seat of EMF of velocity B l of magnitude this plus this minus apply right hand rule and get this voltage. And your electrical circuit corresponding to this is your external battery here which is fixed plus minus, let this battery voltage let me call it v ok. Therefore, there will be some current in this circuit.

Let R be the resistance of electrical resistance of this circuit therefore, i t current in the circuit will be equal to V minus B l v, divided by R, what is R? R is the resistance of this total path, this is the i t. Therefore, why I told i t will become time varying? At t equal to 0 minus switch was opened, it was simply generating a voltage B l v and late V naught is equal to velocity at t equal to 0, what is t equal to 0? When S is closed, so this is the scenario this is i t.

So, this will be the expression of the current understood. So, v i t is equal to B l v minus B, B l v divided by R is the expression of the current. Now here you see there are looks like 2 variables are there unknown; one is i t current because it has become a function of time, it depends upon v, v is no longer a constant thing it started with a constant number v naught, but it will progressively change and i and v both are time varying i t and v t.

So, I need another equation to get a knowledge of how current is changing in this circuit, how the velocity is changing in this circuit and who will supply that knowledge, it will be this electromechanical equation, it is KVL equation in this loop KVL, another is dynamic equation.

What is the dynamic equation? It is this fellow that is the conductor let it is mass let m equal to its mass. So, it is m, I will apply the Newton's rule m d 2 v m d v d t sorry m d v d t the acceleration the force is equal to the force applied. Force applied is how much? F e. Let friction opposing force is 0, friction and opposing force is equal to 0. So, it is this force which is accelerating that is the second equation.

Therefore, m d v d t is equal to F e and F e is nothing but B i into l that is all, this is the dynamics equation of dynamics or I can write m, I will go very slowly, so that you understand B l and for i, I will write this V minus B l v by R, I have eliminated one of the time varying quantities i.

So, for i, I have written like this. Therefore, my it is very interesting see then your equation becomes m d V d t; this is m d V d t.

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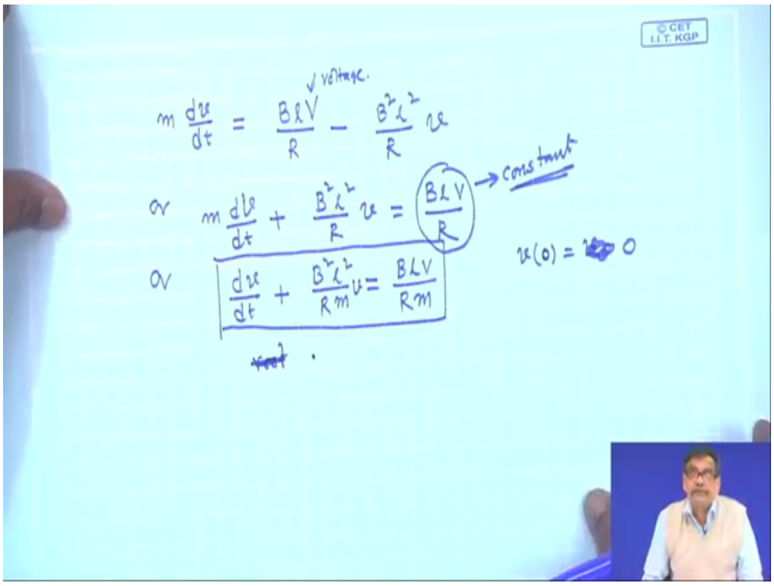

Sorry this is equal to B l V and this will then become B l. This capital V is the voltage finally, this one I am excluding the back end. So, B square l square by R into small v, this is the equation or you will get m d v d t plus B square l square by R into v is equal to B l

V by R this is the equation. This right hand side is constant or you can write d v d t plus divided by m B square l square by R m, what is m? m is the mass of that conductor is equal to B l V by R into m.

So, it is a first order differential equation, with the condition that velocity at time 0 is equal to v 0, suppose initial velocity; no is 0 v 0 is 0, initially it was stationary I have closed the switch, so current has started moving. So, this is our velocity will change. Anyway this is a first order differential equation and the solution of this is so well known, we will not do like that. Only thing is here root is root I will be checking actually. So, we will continue with this in our next lecture.

Thank you.