Course Name: Design of Electric Motors

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Title: Variable Pole Machine Stator Winding Design (Pole-Phase Modulation)- 2

Greetings to all in this lecture, we will discuss the 9 phase pole phase modulated induction motor drive, how the number of poles will be changed with respect to the pole phase modulation. We can see here the generalization what we have discussed in the earlier lecture, the in order to change the number of poles from one combination to other combination, this is first one and this is second one. So, pole change ratio should be odd positive integer and it should be greater than or equals to 1 and the torque equation in terms of output power is directly related. Output power is equals to torque into speed and with respect to the machine modeling equations torque is directly proportional to the number of poles. So, if we will change the number of poles, if p value is high poles, then that type of mode we will utilize it for high torque, for starting acceleration as well as gradient roots at low speed application and next if poles are less in that particular mode, we will utilize it to achieve the high speed cruising purpose.

Let us consider the 9 phase machine.

The example is 36 slot 9 phase 4 pole and how to develop the winding and how to change the number of poles, we will see. The slots per pole per phase is equals to 1 with respect to the 36 slots, it is 36 by 4 into 9 that means, slots per pole per phase is 1, it is a concentrated type of winding and pole pitch is equals to 9. If full pitch winding means it is 9 slots required as a coil pitch, the conductors in first slot and conductors in 10 slots are connected. The symmetrical winding distribution with respect to the 360 by 9, we can see here the vector diagram for 9 phase system and the winding table for 9 phase machine, 9 phase pole we can see here.

The first coil related to the A phase is placed in slot 1 and slot 10. The second coil is placed in slot number 11 and slot number 19 and slot number 28. So, these 2 coils are connected in this fashion that is A phase, then B phase connections in this fashion B phase has 2 coils like this way, intermediate connection is represented here as a green color and first coil is B and B dash, second coil also B B dash. So, it is placed in slot

number 3 and slot number 12 and second coil related to the B phase is placed in slot number 21 and slot number 30. We can observe here the angle between the A phase and B phase is 40 degrees and mechanical is 20 degrees, electrical is 40 degrees because it is a 4 pole machine.

Next C phase is placed at 80 degrees, D phase is placed at 120 degrees, E phase is placed at 160 degrees, then F phase and then G phase, then H phase same way I phase also placed like this 9 phase winding we can make it with respect to the winding table or by utilizing the stubbing manner also we can design the winding for 9 phase machine. Here only slots per pole per phase is coming 1 that means, only 1 coil side has to be placed. So, 1 coil side has to be placed under 1 particular pole that is represented here we can see F S has 2 coils and those 2 coils 1 coil is placed under 1 pole that is 1 and 11th 10th slot and second coil is placed in 19th and 28th slot. The intermediate connection is required these are the 2 coils first slot and 10th slot and 19th slot and 20th. So, these 2 we can connect it this is the blue color representation like this all coils are placed with 40 degree displacement and now we will analyze how the flux lines are forming.

So, this is the A phase winding. So, with respect to the currents 9 phase currents are shown here and how we are generating this kind of 9 phase currents means by utilizing the 9 phase machine and along with the 9 phase drive and 1 side of the 9 phases are connected as a star manner and other side 9 phase terminals are connected to the 9 phase power converter. Here single throw double pole switch manner I have connected all 9 phases with 9 phase inverter also we can connect it and the current I am considering at this particular instant where A phase current is positive that means, here cross and here dot here also cross here it is dot as per the right hand thumb rule we can see the flux loops in this manner for clockwise for a positive current for anticlockwise for current is coming out and similarly here also cross and dots we can see and same manner B phase flux loops C phase D phase flux loops and E phase also we can see with respect to the positive currents all A phase B phase D phase and E phase has positive currents we can see here A phase has positive that is blue color one and B phase also has the positive current C phase also positive and D phase also positive current and E phase is positive from this current waveform we can visualize A to E having the positive currents and B to F to I phases are having the negative current. So, with respect to the negative current now the F phase has negative right here it will come cross because at the F dash point cross will come at F point dot will come current is leaving at the starting terminal of F phase and current is entering at the ending terminal of F phase. We can see that resultant flux loops how it is forming for 9 phase 4 pole machine with respect to the 9 currents for the instant here with respect to that particular instant the flux loops are forming in this manner each and every conductor we have to represent the current like it is cross it is also cross and we have to apply the right hand thumb rule based upon the right hand thumb rule the flux loops are in one particular direction we can see all loops are in the

same direction under one particular pole and it will form one bigger loop and this is 9 phase 4 pole operation and here inverter representation for 9 phase machine have shown.

So, one side it is star connected and other side is connected to the 9 leg inverter. So, with respect to the 9 phase symmetrical distribution we will give the displacement 40 degrees for each and every inverter leg references or waves and PWMs we can generate accordingly and as per the winding table here we can see that the conductors placed in 9 for 9 phase 4 pole operation and 3 phase 12 pole operation we no need to change any winding connections and the poles will form accordingly with respect to the excitation here the windings are connected from first slot to tenth slot and thirteenth slot and fourth slot fourth slot to nineteenth slot conductors are connected this is first coil and this is second coil in a 3 phase 12 pole mode if the coil pitch is what 36 divided by 12 pole right it should be 3 slots we can see the blue color one that is the conventional pole pitch with respect to the 3 phase 4 pole or 3 phase 12 pole machine this is 3 phase 12 pole machine where the coil pitch is equals to 3 1 to 4 we have to make the connection, but already winding is done for 9 phase 4 pole with there the coil pitch is equals to 9 conductors are connected 1 to 10 we can see here 1 to 10 is connected. If we will see the current in both manner either a blue color line as well as red color line current is entering at or that is in the first slot coil side and current is leaving at tenth slot coil side and it is entering again at thirteenth slot because these two are electrically in phase or phase and here also or with respect to the a and g these two are in the same phase that means, again current will enter at this thirteenth slot and current will leave at the fourth slot in a conventional 3 phase 12 pole machine current will enter at the fourth first slot conductor and fourth leave at the fourth slot conductor. Here also it is happening same current is entering at the first slot conductor after making the connections with respect to the tenth and thirteenth coils current is leaving at the fourth coil even though these two connections are not there from tenth to thirteenth coil the inverter is giving same excitation for the both coils electrically in phase these two are and we can see here in 9 phase 4 pole mode all coils are getting 360 by 9 40 degree displacement excitation in 3 phase these 3 windings are coming into the in phase electrically these 3 windings are coming in phase these 3 windings are coming in phase electrically. So, 0 degrees 120 degrees and 240 degrees that means, the if let us consider an instant where a phase d phase and g phase coils are getting positive current and electrically in phase 0 degree and B capital B resultant phase which is a combination of B E H these 3 coils are getting 120 degree displaced excitation and C F I and these 3 phases are getting 240 degree displaced currents.

So, with respect to that thing let us consider the this instant where a phase current is positive is this is this one and B phase current is positive and 120 degree displaced and F phase current is negative F dash here it is means again here it will be cross these 3 conductors are in having the same current with respect to the 120 degree displacement

all are cross means we can see the flux loops are in the same direction with respect to these 3 conductors because these 3 are these 2 are connected sorry here these 2 coils are connected already and these 2 coils are connected with respect to the 9 coil pitch even though it is connected we are able to make the 12 pole operation. So, with respect to the currents cross here and here it will be dot and here also cross and here it is dot same fashion for D E and I D has positive current and it is 0 degree and it is 0 120 240 and I E phase has positive current and it is 120 degree displaced this one and I has negative current and 240 degree displacement. So, here also again all are cross and other side current is coming out that is dot same way we can see the other conductors also apply the right hand thumb rule and find the flux loop direction and here we can see the how 12 poles are forming symmetrically with respect to the given excitation in 9 phase 4 pole mode A phase and D phase and D G phase coils are in 120 degree displacement whereas, in 3 phase 12 pole mode A phase coils D phase coils and D G phase coils are in electrically in phase and similarly these 3 coils are in phase these 3 coils are in phase to make the 3 phase 12 pole combination and how 12 poles are forming we can see in this image and how the rotating magnetic fields will form with respect to the 9 phase 4 pole at the left side and at the right side 3 phase 12 pole we can see these are the ANSYS results like how 9 phase 4 pole mode the flux lines will flow and how 3 phase 12 pole mode flux lines we can see here 3 phase 12 pole mode for high torque and low speeds in this region and in this region 9 phase 4 pole mode for high speeds and low torque operation and these are the different torque speed characteristics with respect to the different machines for 9 phase machines the speed change will be 1 is to 3 ratio we can change that is 4 pole to 12 pole we can change and in 15 phase machine we can change from 2 pole to 6 pole and then 10 pole 1 is to 3 is to 5 and in 45 phase machine 1 is to 3 is to 5 is to 9 is to 15 we can change the number of poles from 2 pole to 6 pole and then 10 pole and then 18 pole and 30 pole if we observe the left side top figure gives the torque speed characteristics with respect to the IC engine this is the conventional electric vehicle torque speed characteristics and here we can see the torque speed characteristics with respect to the 9 phase 4 pole and 3 phase 12 pole mode it is exactly matching with 2 gear torque speed characteristics in 3 phase 12 pole mode we can utilize it for high torque application and 9 phase 4 pole mode we can utilize it for high speed applications the 5 gear or 5 speed 45 phase machine will give exactly similar torque speed characteristics of the IC engine this is the gear 1 and gear 2, gear 3 and gear 4 and gear 5 like this we can change the torque speed characteristics by changing the number of poles the advantage with this kind of machines are we can eliminate the transmission system or gearbox system or we can reduce the footprints related to the mechanical gearbox in various applications like traction and wind energy conversion systems and aircraft applications, propulsion applications and higher fault tolerant capability we can attain we can see here advantages there is no magnets and reduced footprints of transmission and weight of the transmission will come down accordingly and these are the different power

trains with respect to the Tesla model S and Porsche take on and Nissan LEAF and proposed power trains with respect to the multi speed machines the torque density will be improved with the multi phase machines instead of with respect to the conventional machines and here maximum torque per phase we can observe with respect to the Tesla model S the maximum torque per phase is 200 and Porsche take on it is 217 per phase the power rating of the machine is 420 kilowatt and Nissan LEAF the maximum torque per phase is 94 and the rating will power rating of the machine is 80 kilowatt if we design the machine for 370 kilowatt with respect to the 9 phase machine the torque per phase will be 500. So, we can increase the torque density by utilizing the pole phase modulation based machines those who are interested to see the different machines with respect to the pole phase modulation they can go through these references and these are the few literature related to the existed electric vehicles and with respect to the torque and power ratings and interested people can see these references for pole phase modulation based induction machines with this I am concluding this lecture. In this lecture we have discussed the 9 phase machines how we can change the number of pole sun phases by utilizing the pole phase modulation technique.

Thank you.