NPTEL Online Certification Courses
Industrial Robotics: Theories for Implementation
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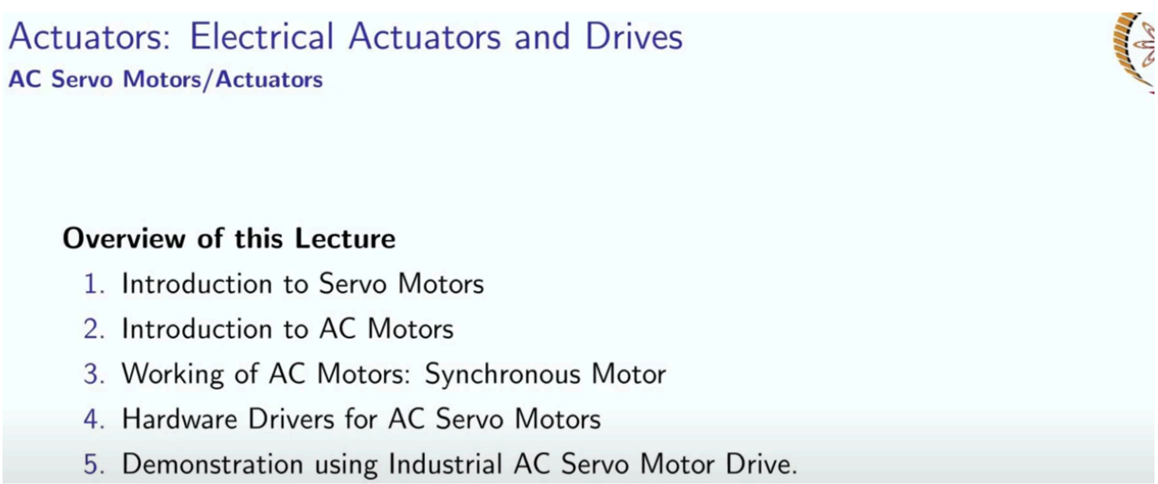
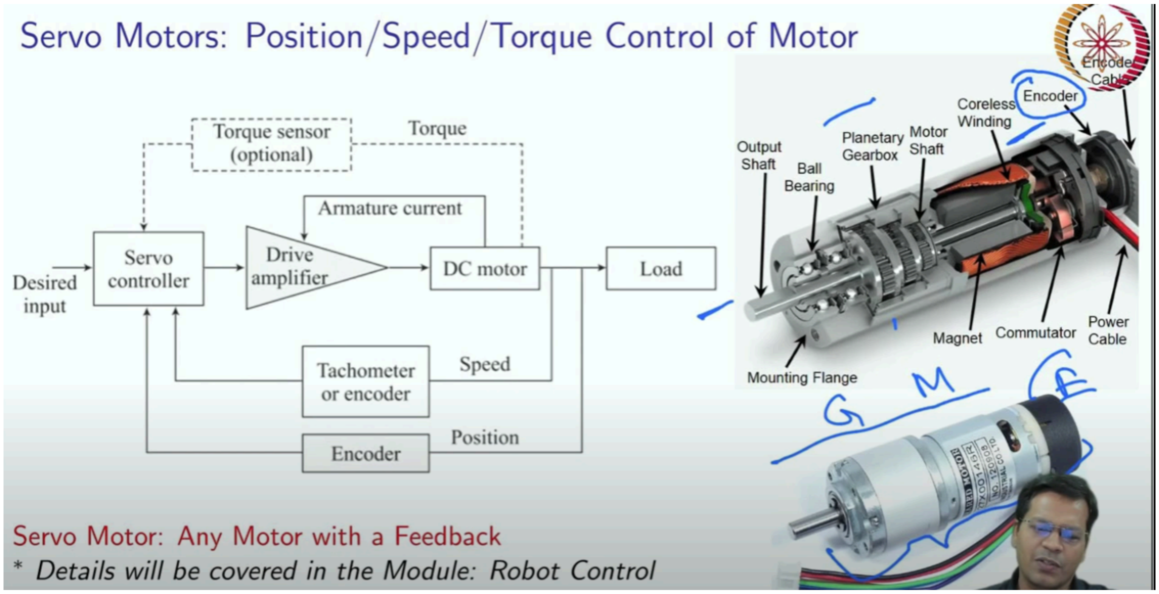
Lecture: 10

AC Servo Motors

Welcome back. So today, we begin with the last part of the module actuator, that is, industrial servo motors and AC servo motors, to be more specific. So, so far, we have already discussed very much upon DC motors. We proceeded further, and we started learning stepper motors, and then we continued with BLDC motors. Whereas those kinds of motors are very good for compact robots or robotics or small kinds of robots in industrial robots which are of heavy payload kind they are mostly using AC servo motors because of various reasons we will discuss today. So yes, we will start today with the following outline of the lecture.



These are a few. So yes, today we will begin by introducing you all to servo motors. Servo motors, what it is and introduction to AC motors as such. What exactly is a servo motor? Servo motors are not always AC motors. So, we will specifically talk about AC servo motors today, and then we will proceed with the working of AC motors, a specific kind of AC motor which finds its application in industrial robots is the synchronous AC motor. We will discuss how it works, and we will discuss the hardware drivers for AC servo motors. Finally, I will show you a demonstration of a simple AC servo motor drive using a standard industrial servo motor drive.



So, here we begin today with servo motors AC or DC. So, what exactly is a servo motor? So, you see, servo means feedback. So, you saw your DC motor, as soon as you give it a voltage, it starts moving. It will start spinning, but if you want to stop it at a particular position, you have to be very specific about the kind of controller which it can use.

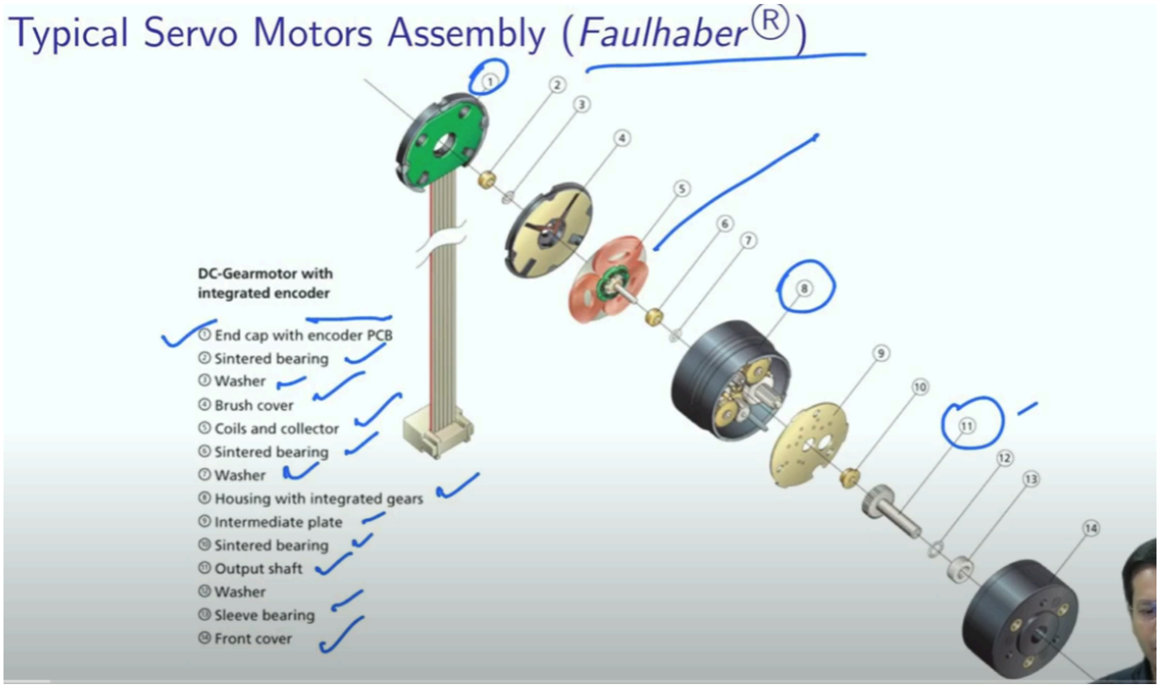
So, if you want to stop it anywhere in between at a particular angle, you need to have something which is known as an angular position sensor. So, that will give you feedback on where I am where the motor is, and then it can, you can have a sort of controller which can exactly compare with the desired angle where you want and you can stop it. So this is a type of servo which I am talking about. So, this is a general layout of a standard servo motor. In this figure, I have shown a DC motor. It can also be an AC motor, can also be a BLDC motor. It accepts some kind of signal to control its position, and the output is torque, which it can provide, and you are loaded with some kind of load. It can be a simple link of a robot arm, and then there are sensors. There are sensors as I said, that can give you feedback in terms of speed it can give, it can give you a position feedback also. So yes, position feedback can be encoded in terms of digital values, and finally, it goes from the encoder to the servo controller. Using this position, feedback desired input is compared, and that controller gives you a kind of signal to the motor driver. The Motor driver finally feeds that value to the motor. So, the Drive amplifier is your driver. Driver or power amplifier or drive amplifier, whatever you can call it.

So, you can also have feedback, which is torque feedback using some kind of torque sensor or joint torque sensor and that can also be compared. So yes, this is a kind of feedback. So yes, using these kinds of feedback, this kind of feedback you can have a controller which gives you a signal which can be fed to the amplifier, a power amplifier which is capable enough to do all these types of control, not all these. You can be happy with just having a position control. So yes, this is a kind of closed-loop system.

Let me just draw a simple system. So, you desire a position. Position, you have a summing block here, you have an encoder, encoder here. So, this is your controller, this is your controller, this is your motor, and finally, it gives you an output. It is your feedback-sensing device. So, let us say over here, I am taking a position; this is the actual position, and it is loaded by a kind of load. So, here your load goes. This time, it is only a position controller. So, the error from here is fed to the controller. The controller gives a kind of signal over here. Let us say it can give you current and finally goes to the motor, and the motor runs. So, this is a closed-loop operation, which is there, and that is what is utilised by the servo motor. So yes, the servo motor is nothing but any motor, not just a DC motor with feedback. So, many details will be covered in the module robot control which is there at the end of this course.

So, this is a typical DC motor that supports you with all kinds of pre-requisite which is required to do servo control. So normally, a motor runs at a very high speed, so you need to have what is known as a gear box, a reducer which can reduce the speed so that you can control it precisely. Moreover, it also gives you a torque enhancement. If you reduce the speed, you will get higher torque. So, from there, it goes to the output shaft.

So, gear reduction is already there in place, and then this is all commutator, their brushes and all those stuff that is part of the motor. Now, you have what is known as an encoder, which can sense the angle and give you feedback. This is all. So, you have what? You have an encoder, which is here. You have a gearbox, which is here, and then you have a motor, which is here. So, overall, this set completely makes it a kind of servo motor-capable device. This is a motor with some attachments, so it is not a servo until and unless it is controlled by some means. So, this is a typical servo motor.



So, now, a similar one is all in one kind of unit. So, you see majority of the things are for the construction of this type of compact device. Important ones are what you can see here is your PCB, which can sense the angle, and this is the gearbox which is there and the output shaft. And the driving mechanism, definitely. So, this is the coil, and you have a commutator, or it may be a brushless DC motor also. So, this is what is a typical construction of a servo motor assembly.

AC Motors and its Advantages

Operation: AC supply is directly connected to the electromagnets that creates an alternating poles. The magnetic field generated due to set of stator coils appear to rotate.

Advantages:

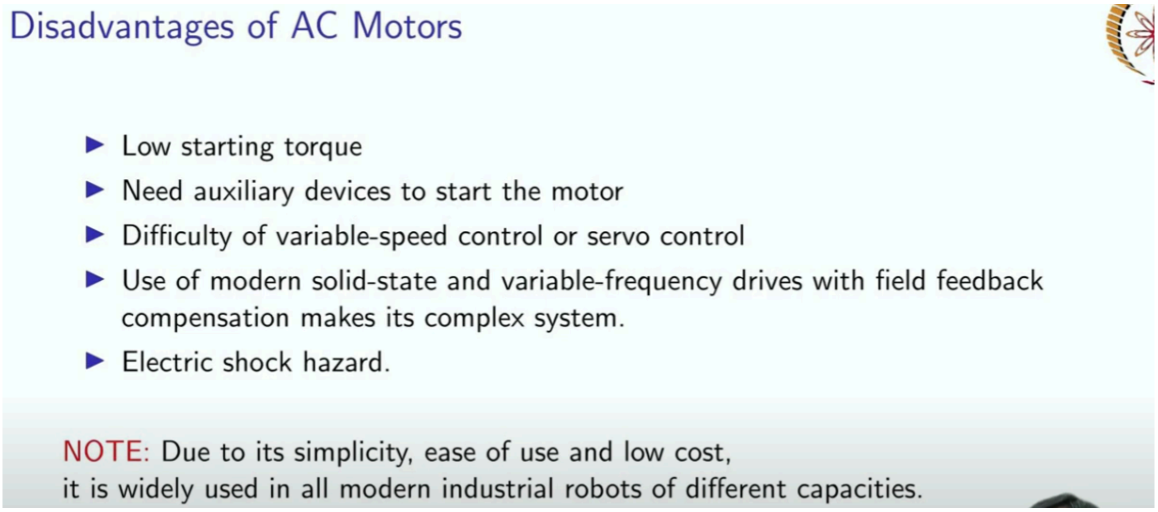
- Inexpensive due to less number of parts.
- Convenient power supply.
- No commutator/brushes, and its associated problems of arcing and wear.
- Low power dissipation
- Low rotor inertia making it responsive
- High reliability, robustness, easy maintenance, and long life.

So, operation-wise, the AC supply is directly connected to the electromagnets that create an alternating pole. You know already by your earlier knowledge what you saw is there is a magnet, there is a magnet in between you may have a shaft, and you have a coil that goes like this, and it is wound like this.

If you flow current like this, this becomes north, this becomes south and then you also saw you can have these kind of poles which are like this which are at different places. So, you can have a pole which is here. You can have a pole which is opposite poles which are there. So, all together, you have three phases that can create an equivalent magnetic field which can rotate. So, this is the same principle which is applied here. So, the magnetic field generated due to the set of stator coils appears to rotate just like the BLDC motor we did. We will do this also. Here, we will supply it with a pure AC signal. So advantages are it is inexpensive due to less number of parts because there is no commutator here, there are no brushes here and straight away you can supply the AC signal which is already in hand at your home at various places. So, connectivity is a very, very convenient power supply. It is available everywhere AC is available everywhere.

So yes, that is the reason and no commutator, no brushes and the associated problems of arcing and wear that are very, very common with standard DC motors but not with BLDC motors as such. It has a low power dissipation because there are no brushes and low friction so that it can dissipate less power. So, there is no part which can dissipate energy in any form. Only it is dissipated as heat energy due to the resistance of the coil itself; otherwise, very little dissipation is there due to the bearings only. So, motor inertia rotor inertia is designed in such a way that it is low. So, those kinds of rotors are very, very responsive.

You apply a current, you generate a field immediately your rotor can follow the rotating magnetic field. They are very, very responsive. If it is a bulky and heavy rotor in that case, it will be a little dumb kind of. So, it won't respond so quickly. So, that is the reason it is made very light. It is highly reliable, robust, and easy to maintain and definitely, for these reasons, it has a longer life also.

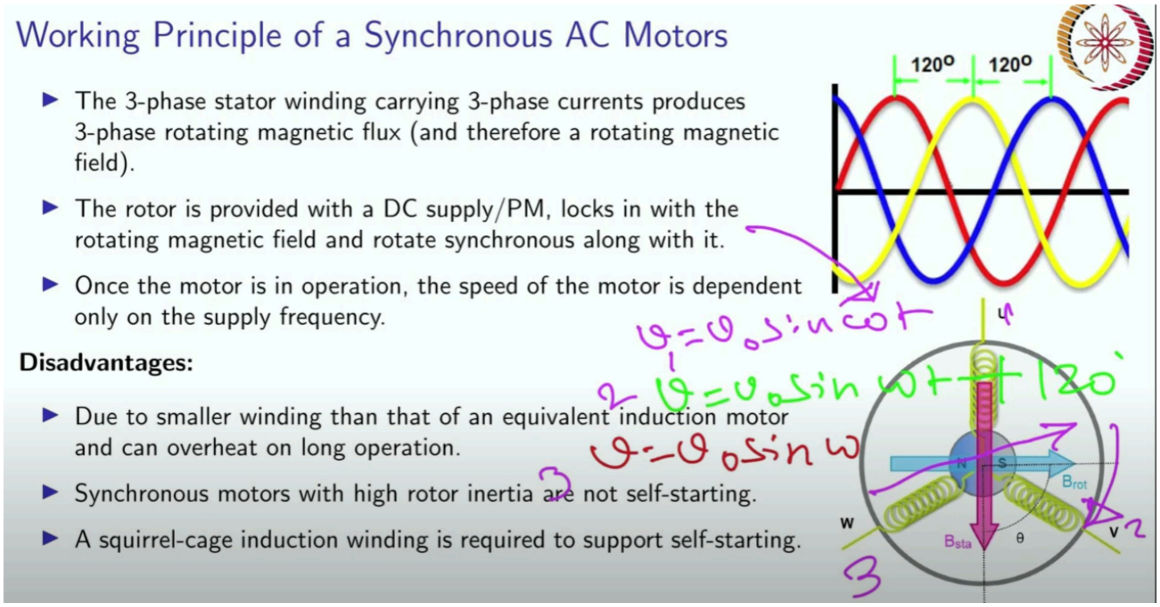


So now, let us just look at the quick disadvantages of AC motors. They have a little less starting torque. So, it finds some difficulty in starting; otherwise, if it is running, you can continuously keep it running. So, starting-wise, it needs to have some kind of auxiliary device to start the motor.

Sometimes you have a coil, which is something like an induction motor, so it starts like an induction motor, your fan, and then it becomes a synchronous motor or any kind of AC motor, or there are some devices also star delta kind of starter systems are there. There are many other similar approaches to it. So, it needs an auxiliary device to start the motor. Difficulty of variable speed control because you know you have fixed frequency at home it is very, very difficult to change the speed of such kind of motor. You must be thinking we are easily controlling the rotation rpm speed of our fan.

Yes, we are doing so. We are wasting a kind of energy sometimes in resistance, sometimes in capacitance, and sometimes we are losing the torque while doing so. So that is what we cannot sacrifice when it comes to driving industrial servo drives where torque is very much a prime thing. So yes, you have to maintain the speed without losing much of your torque. So yes, you have a kind of thing which is known as a servo control.

We will discuss this now. Use of modern solid state and variable frequency drive here is the term for that modern thing. Yes, variable frequency drive with field feedback compensation makes it a complex system, but yes, without this, there is not much of an alternative. So we should be happy with it that nowadays, with modern electronic systems, this has become a quick possibility and it is quite inexpensive nowadays. So yes, there is definitely some shock hazard. You have to be a little careful; the rest is fine. Note that due to its simplicity, ease of use and low cost, it is widely used in all modern industrial robots of different capacities because it can provide you with a huge amount of power, which is not possible with small DC motors or sometimes even BLDC motors. So, that is the reason we have to stick with AC motors if we talk about big robots that are there in the industry.



So, let us just discuss the working principle of a synchronous AC motor. So yes, as I have told you have a three-phase stator winding carrying three phases of currents that produces a three-phase rotating magnetic flux and, therefore rotating magnetic field. So yes, just now, I have shown you that you have multiple poles which are there, so you have poles here, you have poles here, so you have another pole here and pole here, you have yet another pole here and pole here. So, each one of them can be north-south. If one is north other one is south. So, this can create a field, which is a field which can rotate. So, this field can rotate. So, alternatively, you can shift the pole from here to here, you can shift the pole from here to here and your armature keeps on following the rotating magnetic field. So, this is the principle which remains here also.

So, the rotor is provided with a DC supply, so your rotor is provided with a DC supply that is a kind of magnet which does not change its polarity, or it can be just a permanent magnet it can just be a permanent magnet which locks in with the rotating magnetic field and rotates synchronously along with the rotating magnetic field. Once the motor is in operation, the speed of the motor is dependent only on the supply frequency. So rotating magnetic field is because of a fixed frequency supply.

So, the rotating magnetic field rotates with the kind of frequency of the input AC supply which is there. So, in order to change the speed, you have to change the frequency.

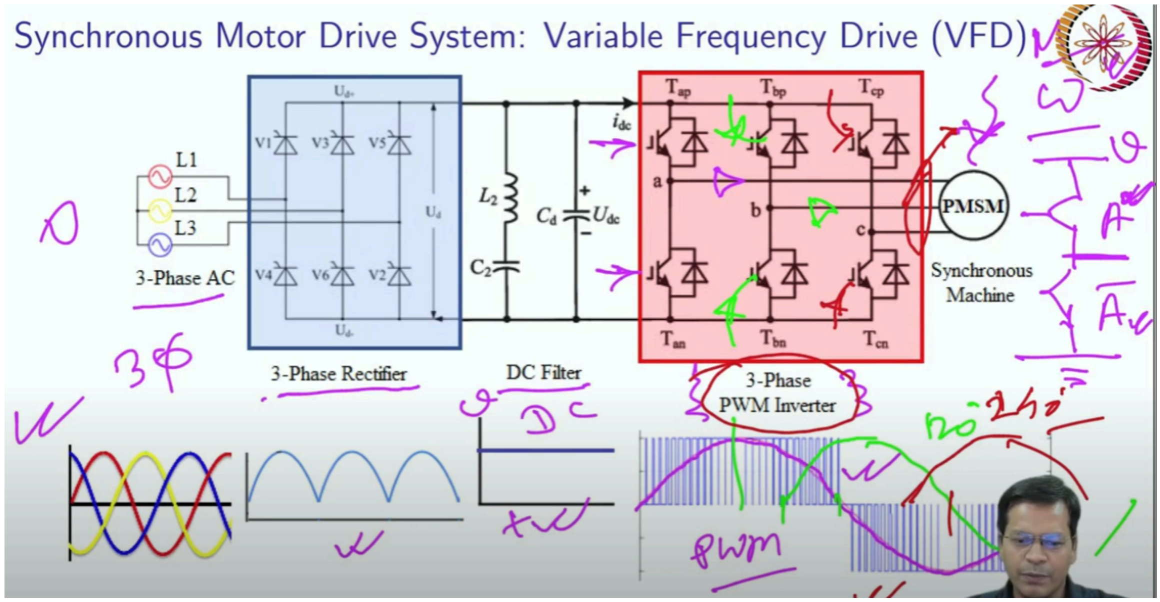
So, there are a few disadvantages to this also, so because of its compact nature, heat dissipation is a problem. So yes, with smart designs nowadays, it is now a possibility to design it very small, but yes, that heating is a problem, so you need to have a good arrangement to dissipate that kind of heat which is generated while it is running.

So, synchronous motors have a high rotor inertia because you know it has magnets. Now you know it has a permanent magnet or maybe some excited coil, so that makes it very heavy. So, that is the reason it does not pick up speed immediately on applying a rotating magnetic field. They do not have some self-starting kind of sink. So, a squirrel-cage winding; induction motor kind of winding is there to self-support this kind of starting problem. So yes, that is there, and you see quickly now.

So, this is the three phases I am talking about. So, now again, star connected, we discussed very much in detail while we were discussing the BLDC motor. So, you see here also. Let me just vanish myself from here. So yes, this is there, so one of them, let us say if it has V is equal to V0 sin omega t ($V=VoSin\omega t$), other one will be the next one will have a voltage, which is something V is equal to V0 sin omega t plus 120 degrees ($V=VoSin(\omega t+120°)$). The third one will have a value, which is something like this V is equal to V0 sin omega t plus 240 degrees ($V=VoSin(\omega t+240°)$).

So yes, it should be something like this so that all the phases are there. All the phases are part of three phase AC supplies. So, this creates a rotating magnetic field here. So, you see now, if one of them has this one supply, two supply and third one, so one, two and three, this will create a field which is rotating in nature, and that carries a rotating magnetic field. So, everything depends on the kind of frequency which is supplied from here.

The frequency which is supplied here. So, this is the frequency. So, with this frequency, the field will rotate. So, this carries the armature along with it. So now, the rotor, which is also the armature, has a permanent magnet that follows the magnetic field. This is how it works.



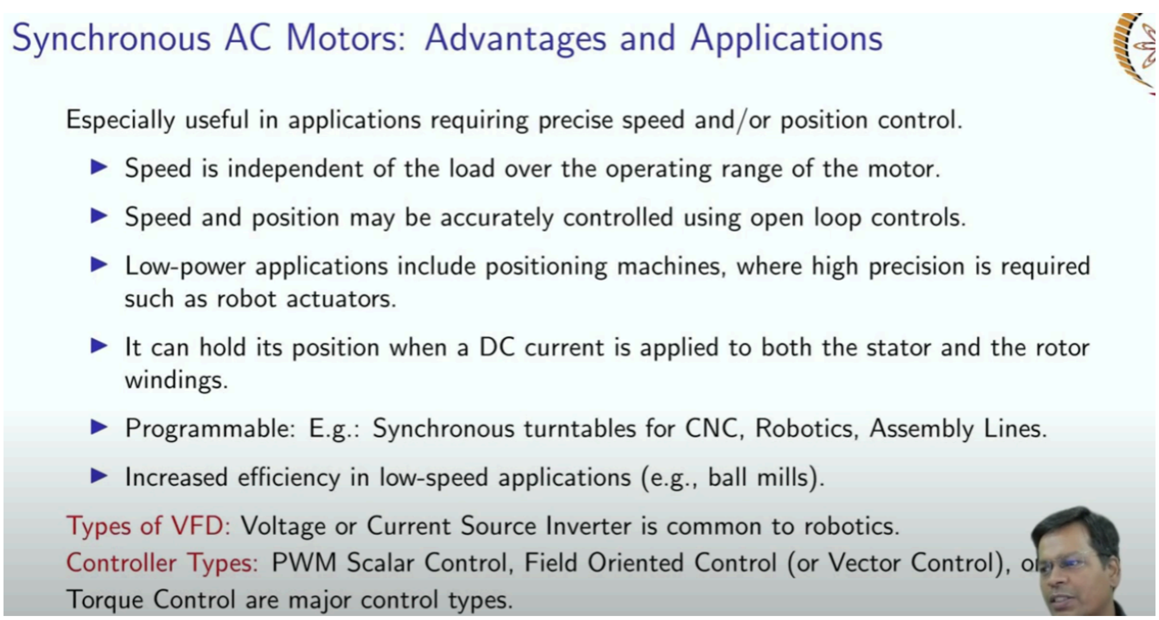
So now, let us move ahead. So how to do that? You cannot create a variable frequency out of because you know now you have to have a rotating magnetic field with a different speed. So speed of that rotating magnetic field is dependent on the frequency which is supplied from the AC supply. So yes, in order to control omega, it is very difficult to use the standard AC supply three-phase AC supply and do that. So, what we do is we first do this.

So yes, you are supplied with three-phase AC. So that goes here. This is a three-phase rectifier and a filter. Finally, you get, so after three phases of rectification, you get a supply, which is something like this. So, once you filter it, you get a DC. Got it? So, ultimately, you have converted a three-phase signal to a DC signal. Straight to this is the voltage; this is time, so it remains constant. So, that is a DC supply. So, with this DC supply, now you have a three-phase inverter over here. What it does basically again, if you remember, we have talked about this kind of switch, okay? You have talked about this kind of switch where you have two switches, A and A bar, that are used to switch the polarity, which is here. Polarity, which is here. So, similar is the thing which is here for three phases again, just like a BLDC motor driver. So, what it does it can gradually it can gradually switch its polarity from switch the pole from here to here. Okay, from here to here. So, in order to do that, each one of them is supplied with a kind of PWM signal pulse width modulated signal, which is nothing but a variable duty cycle square wave signal. So, you see, the density varies like a sine wave. So, the equivalent voltage that goes here and here is controlled.

So, the equivalent voltage that goes here and here is controlled. So, what is happening here? So, you see a sinusoidal signal kind of current you can get. Okay, so this wire gets a signal, which is something like this. So, effectively, now this one, this one, the second one over here (T_{bp}) and here (T_{bn}) will see a signal which is phase shifted by 120 degrees. Okay, and that also will be that also will be something. It will start from here. It will go like this and follow something like this. Okay, So yes, this is 90 degrees, somewhere between 120 degrees and 180 degrees.

So yes, it starts from here. It follows a phase-shifted one, and this is a different waveform which is V is equal to V0 sin omega t plus 120 degrees. Now, the third one the third one is triggered here and here, and there is another yet another waveform that is starting somewhere over here, and that goes like this again. Okay, so that is V is equal to V0 sin omega t plus 240 degrees, not exactly 360 degrees, so 240 degrees starts. This is 270, so it is in between this. So yes, this wire will see a signal which is phase-shifted by 240 degrees. So, this is actually creating a three-phase signal over here three phase signal over here.

Now, we started with a three-phase. We are ending with a three-phase. So, what is the beauty over here is you have full control over this signal that is input to this PWM inverter. So, this inverter can now generate a frequency of our requirements. So, this AC which is coming here, the AC which is fed to this motor ultimately is controlled. Okay, so the input frequency cannot be controlled, but the output one is in our control. So, your PMSM, which is a permanent synchronous motor, is now fed with the AC three-phase AC for which your frequency is under control, and you can have a variable speed rotating magnetic field, and you can control the speed of your motor. Got it?



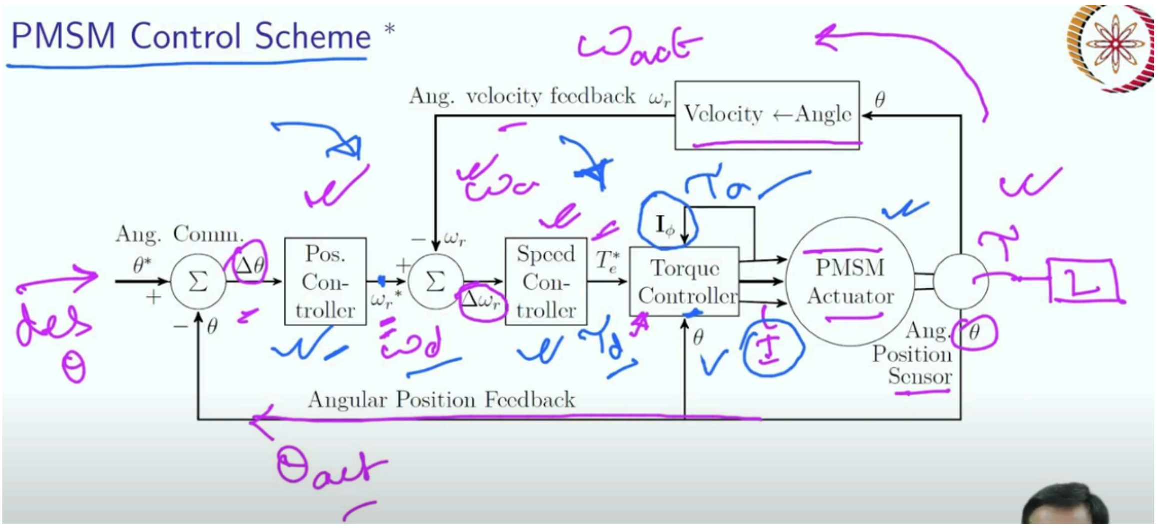
So now, synchronous AC motor also has got some advantages. We will see it here. So, especially useful in applications that require precise speed. This kind of robotic arm requires precise speed or position control most of the time. So, speed is independent of the load. You see, if you increase the load, your speed is not going to vary. Suppose you have pre-calculated it well. You know how much torque is going to come. It is not going to slip over torque. In that case, it will simply follow the speed at which you are supplying the frequency of the AC supply that is fed out of your variable frequency drive. So, your rotor will rotate at exactly the frequency which is desired by the variable frequency drive.

So yes, it is independent of the load. Now, speed and position: position may be accurately controlled using open loop control. Yes, so if you stop it somewhere in between, so if your three phase, let us say you had a three-phase that had some kind of voltage, and I stopped somewhere in between. Each one of them is halted. Okay, so all the poles which were oppositely placed have a particular value and it remains there. So, your field stops rotating, but that is a field. Your magnet will get stuck there. Okay, your magnet, that is the rotor, will stop there. So, that is the holding torque that it will get. Okay, so you can stop your omega anywhere omega can become equal to zero. In that case, your field does not rotate. It remains where it is, and your armature also remains there. Okay, so it can stop also or it can reverse its direction also got it.

So yes, omega can be positive omega can be negative also. So, low-power applications include positioning machines where high precision is required, such as robot actuators. It can hold its position when a DC is applied to both the stator and rotor winding. It is just like a DC voltage is not varying it remains there. It is just like a DC, so you can make omega is equal to zero. Omega omega everywhere. So, you just remember V is equal to V zero sine omega t plus five. This is the signal which is going to the different coils. So, this is what the omega I am talking about. Okay, this omega can also be equal to zero.

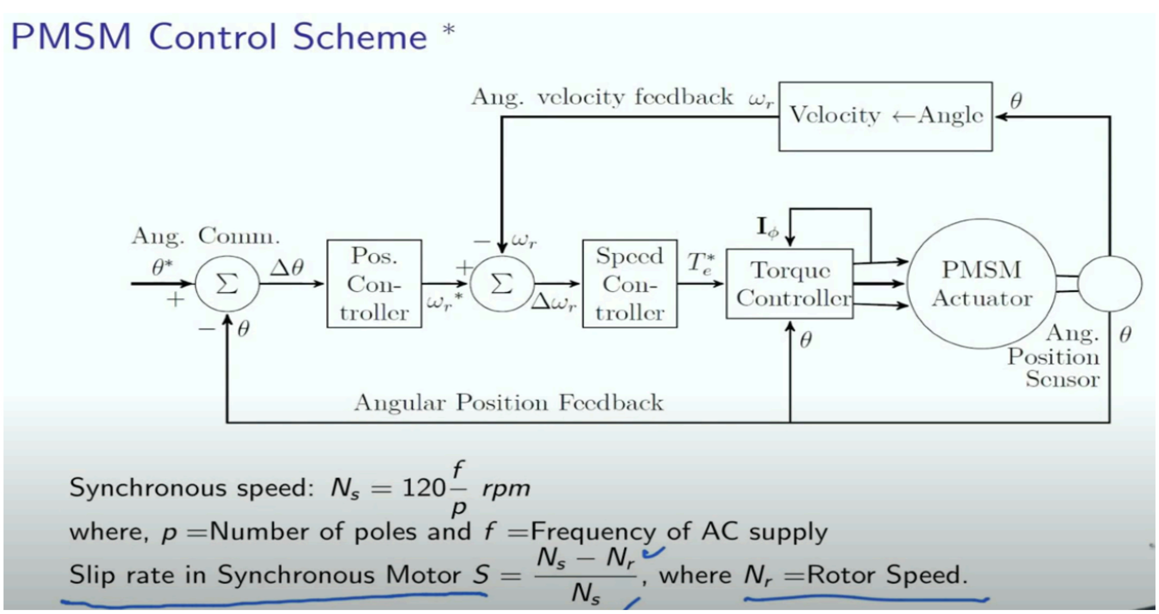
In that case, the voltage becomes constant. You see, this is a constant for a particular coil. So yes, it is programmable. This VFD has some controller in between which can take up the signal which can feed the desired signals to the coils. So, the VFD has got some input device that actually controls the omega rotating magnetic field, which it is able to generate. So, that omega can be controlled directly using that. So yes, that is definitely used for turn table CNC robotics assembly lines. So, it has very good efficiency in low speed applications also. It doesn't find its application just in high-powered industrial robots, it has many other automation applications it is used. Okay, so the type of drive as we have discussed now, is the drive of variable frequency drive.

Okay, it is of various types. It can be a voltage control, or voltage source inverter, or it can also be a current. So, you can have a current which is like this. If you want to control the torque, you have to use current-based; otherwise, for speed control, voltage one is quite commonly used. So, that is commonly used in robotics both kinds. So, the controller type can be a PWM scalar control. All these kinds are taught very much in electrical engineering. We will just get the names of them, at least here, so that you can have some analogy with your understanding here. So yes, the PWM scalar control is there the one which you saw here. Use some kind of PWM signal that is a scalar field-oriented control that is a vector control. So yes, those kinds of direct torque control are. These are some major types. There are many other types of controllers which is there which can control this kind of motor.



So yes, this is the complete picture of a typical permanent magnet synchronous motor control system. So, you see, it has everything here. So, this is a torque controller. This is a torque controller which ultimately controls the feed current to this motor. So, this may be a current control drive. So yes, so current is fed here to this permanent magnet synchronous motor actuator and finally, you are getting some kind of torque here, which is now connected to a load, maybe. So, that is connected with a load, and you are sensing what you are sensing the angle position and position is fed back here fed back here. It is compared with the desired angle and the actual angle. So, you take the difference of that that is the error. You have a position controller over here. Maybe a PID controller most of the time you have a PID controller maybe a PID controller most of the time. We will discuss PID controllers in the last part of this course also. Okay, so this is your final kind of signal, a velocity signal that it is feeding. So yes, it is relating the error to the velocity which is desired which go which should go to the motor if it is connected directly. So yes, now you are seeing the actual angle, which is going here, and you are calculating maybe a differentiator circuit, which is here, which is able to calculate omega, that is, the angular velocity of the shaft. This is the actual again actual omega, which is fed back over here. So, this is the actual omega. This is the desired omega, so the actual omega and desired omega. You take the difference. The difference between those two omegas' angular velocities is now fed to the speed controller. So, a speed controller gives you an output in terms of torque. It gives you output in terms of torque.

Now, there is an interesting part over here. So, you see a difference in difference in difference in angle. You are feeding angular difference, and you have a controller which gives you a desired omega, that is the angular velocity. Now, you are sensing that you may have direct angular feedback over here or you may just have a velocity sensor which is taking the omega. So, you don't need to convert the angle to the velocity rate of change of angle using the rate of change of angle. You can directly get the velocity feedback, and you can compare over here in this controller in summing block, and finally the difference is going to a speed controller that is output gives you an output of torque. Now, you need what this is the this is the desired torque. This is the desired torque. So, how much is the actual torque? So, in order to get that, you have a model of your system most of the time. Okay, you have a model that actually calculates how much the model of the motor may be or the model of the system, which is all attached to this actuator. So, that model gives you by measuring the current (Iϕ) in its coil. It is able to estimate the actual torque. It is able to estimate the actual torque. So, this is the desired torque (Td). This is the actual torque (Ta) difference used by this torque controller. Ultimately, it gives you a current output. So current is finally fed to this. So it is a three-independent controller which is going one by one. So, inside one is the torque. The next upper one is speed. The next upper one is the position. So, you are able to control the torque. You are able to control the speed. You are able to control the position. So yes, you can have somewhere in between. See, this is desired; you can have some desired input velocity fed in between over here (□r). Instead of calculating the desired signal, you can have direct velocity feed from here (Pos. controller). You have just to discard the outer loop which is before today.

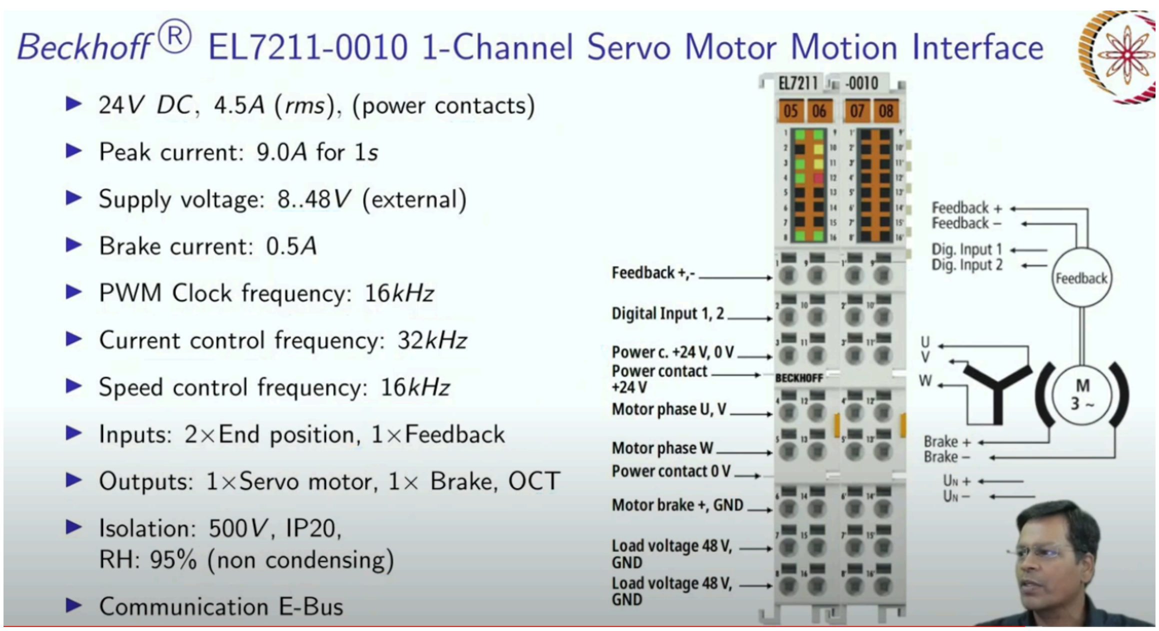


Similarly, you can have torque feedback torque desired torque, which goes here. You just have to ignore the rest of the upper loops. So, direct torque control is possible. So, this is a permanent magnet synchronous motor control scheme which is there, and this is normally embedded inside your standard AC servo motor driver. So yes, synchronous speed. If you have a background in electrical engineering, it should be quite good enough. So, it tells you synchronous speed is equal to 120 f by p.

Synchronous speed: $N_s = 120\frac{f}{p}$ rpm

where, p =Number of poles and f =Frequency of AC supply

For those who are not from electrical engineering, this is a ready-made formula that gives you a relation between the synchronous speed depending on the number of poles you have. It is not just three pairs of poles. There are p number of poles which is here. So, in that case, the frequency of AC supply gets further divided by this okay. So, your ultimate synchronous speed is equal to 120 f by p. f is the frequency of AC supply. p is the number of poles. So, ultimately, this is the speed with which your magnetic field will rotate. So, slip if at all it is having a load which is more than desired. So, there is something a term which is known as a slip rate in a synchronous motor. It is an undesirable thing in the case of robotics. You should not slip anywhere, okay? So yes, this is your slip error in the rotating magnetic field, whereas the actual rotor speed is something different. So, the difference goes here and the denominator. You have the synchronous speed. So, it is sometimes expressed as a percentage. In that case, you just have to multiply this by 100. That's all okay.

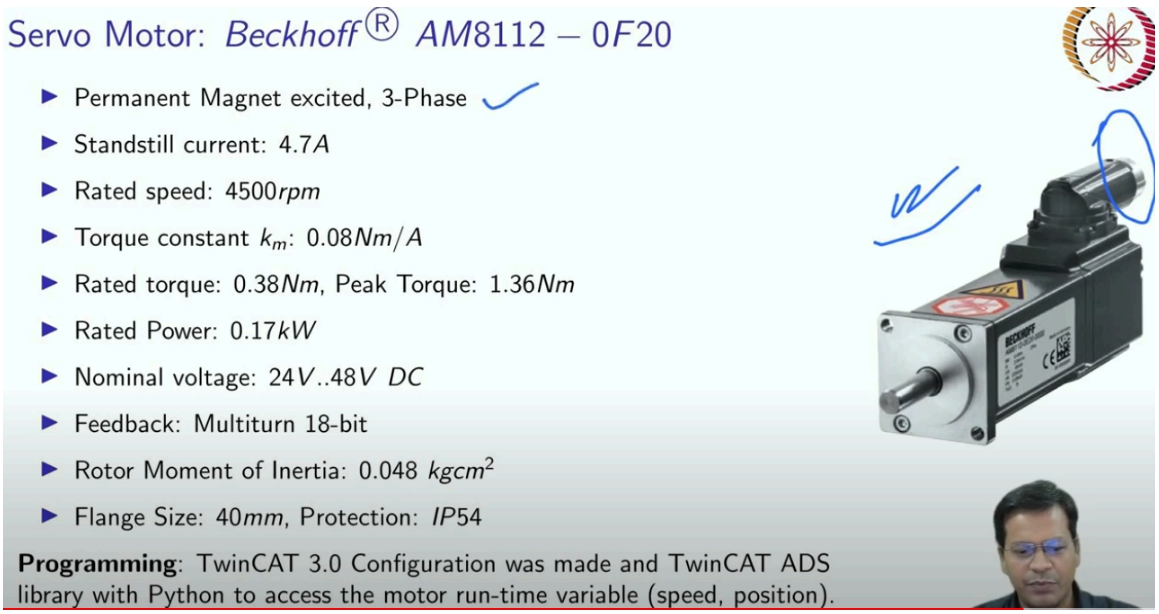


So, this is this is your standard servo motor controller. So yes, this is one such controller which takes care of everything. It can directly take in input through the E-Bus system. So this is your E-Bus system with which you can feed in the signal. It is connected in a bus fashion you have seen earlier. So, this is this can run using a 24-volt DC signal. The maximum current that it can take up is a 4.5 ampere RMS signal that goes to the power contact. Power contacts are here. So, peak current of at least one second, it can handle up to 9 amperes. So, you should be very, very careful if your robot collides somewhere. It should not remain in that position without getting switched off automatically. So, you should not go beyond one second with this much current.

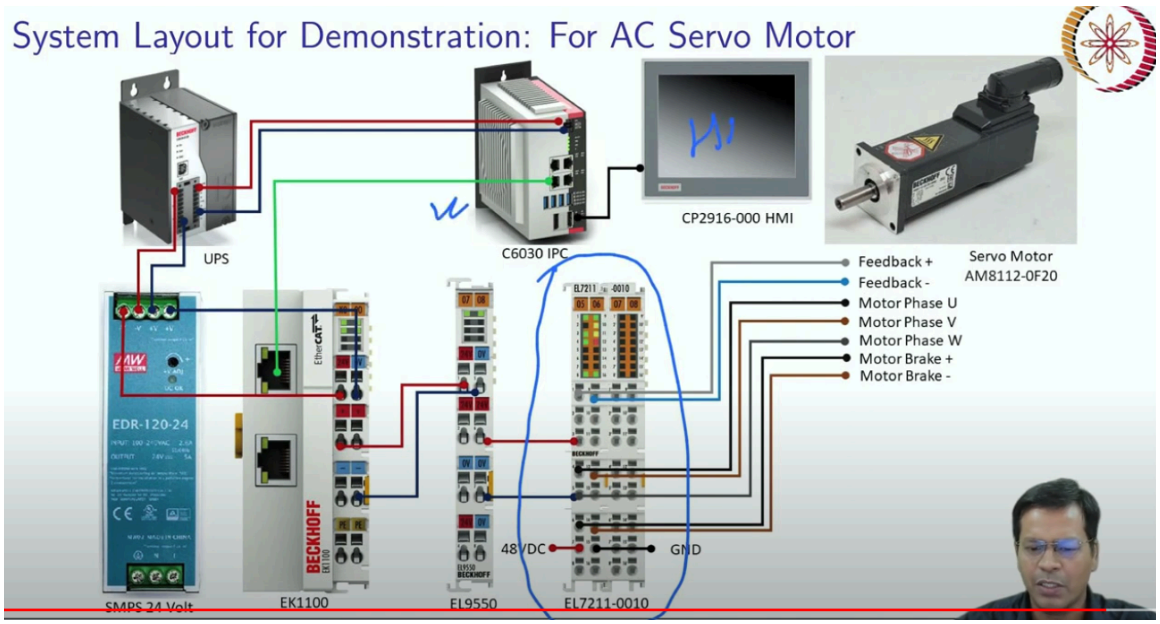
So yes, supply voltage can be anywhere from 0 to 48 volts, which is an external supply that is for the motor, whereas 24 volts, which goes here, is not for the motor. It is for the control system. So, brake current is something like this, so your motor may have a kind of brake shoe which holds your rotating shaft. So, that also uses electromagnets to energise that. So, that is we can draw some kind of 0.5 amperes for this type of motor. So, this is there, at least in this motor.

So yes, the PWM clock frequency is 16 kilohertz, and you see there is a current control frequency. So now, the controller you saw earlier now, you look at very carefully. So, there are different frequencies for each loop. So, this (Pos. controller) controller works with different frequencies. This one (Torque controller) with a different frequency. This (Speed controller) one with a different frequency, and you see here, so the highest frequency with which it is working is the current control loop, and then you have a speed control frequency is something around 16 kilohertz. So, speed control is 16 kilohertz. The current control is 32 kilohertz, and as an input, it can have an end position so that it can stop at the extremes. It can have one feedback from the encoder or maybe a resolver. It can have different kinds of angular feedback. So, that can be taken up by this kind of servo drive. The one which I use this one is it can take feedback which is very much like an optical encoder. So yes, that goes here.

So, output is nothing. It is servo motor output that is UVW three-phase output. So, one doesn't mean just one wire. It has three wires. Similarly, for brake it has two wires okay. So, that goes here that is to apply the brakes, and it is all this in one cable technology which is specific to Beckhoff. Other motors may not have such. The one which I have here today, you just see it carefully. So yes, I'll just make myself a little bigger now. So, you see this one. So, what does it look like? It has two wires. So, first side, you see what all the parts it has. This part is the motor okay. This part is the motor. This is the shaft which can rotate. So, I can feel the tuck tuck tuck. This kind of stops there because it is a permanent magnet which is mounted on top of this rotor. So yes, it is there, and this cage must have poles which create some rotating magnetic field which is followed by this one. So, what is the at the end? At the end of this section, this section is nothing but an encoder. So, you have two separate wires. So, one is for you; see, this one is for coder wire. So, this is this is having I can see, plus VCC ground and three signals. So it may be a kind of resolver give which gives you an output in three different wires, okay? So yes, and then this is three phases and one ground, four wires. This goes to the motor part of it. So yes, this is what it looks like. This is a Panasonic one. There are many other makes which are making this kind of actuator. So, let us go back to my normal form. So, I am back. So yes, this is your thing, and then isolation definitely is an industrial motor. So isolation is something around 500 volt IP20 class ingress protection and relative humidity non-condensing is something around 95% it can handle and communication it uses e bus e bus okay. So that takes up that can change all runtime variables. That is accessible to the twin cut system that I commonly use to demonstrate all these I have shown so far.

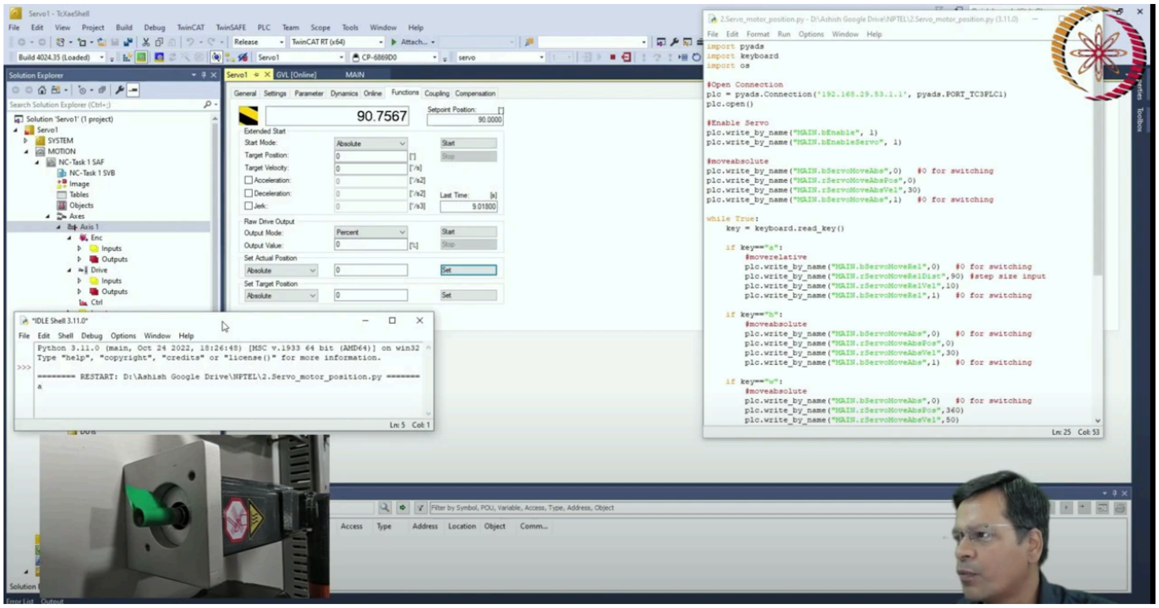


So yes, this is the motor which is I which I am going to use today. So, this is a standard servo motor AC servo motor similar to the kind that I have shown, but yes it has just one cable technology. So, your encoder wire and your power cable both give go from a single bonded cable. So, doesn't matter even if it is separate. So, this is a permanent magnet excited three-phase 4.7 amperes when it is at a standstill. Rated speed is 4500 rpm. So, it requires a gearbox if you have to control that to enhance the torque also and to reduce the speed. So, you see the maximum torque, which it can provide is the peak one is 1.36 Newton meters, whereas it is rated at 0.38 Newton meters only. So, this much is not sufficient to drive industrial industrial robots. So, you need to have some kind. Let's say you have something around 100 times gear reduction. So, this is approximately going to give you 38 Newton meters of torque. So yes, this is sufficient to drive industrial arms and industrial robot arms. So yes, this is sufficient for at least the last three links, okay? So, this is there. So, your gearbox will enhance the torque at the same time, it will reduce the speed. The rated power for this one is 0.17kW specifically, and the nominal voltage is something around 48 volts so I will be supplying multi-turn feedback. It has feedback of something around 18-bits. 18- bit of feedback. So, whatever the type of encoder is here, that is now encoded in a bit of fashion digital way to an 18-bit signal. So yes, you can understand now how precisely it can give you feedback, okay? So, the rotor moment of inertia will be later used to create a row controller model for it. So, this is the rotor inertia. Lighter is better. You now know they are more responsive plan size is 40 mm. Depending on your application, you have to select one of them. Protection is IP 54. Again, I am going to use the twin care three configurations that I made, similar to the DC motor or, BLDC motor or stepper motor. We do a similar sort of arrangement here also, and I will be using the TwinCAT ADS library that I will be importing to the Python environment to access the runtime variable speed and position.



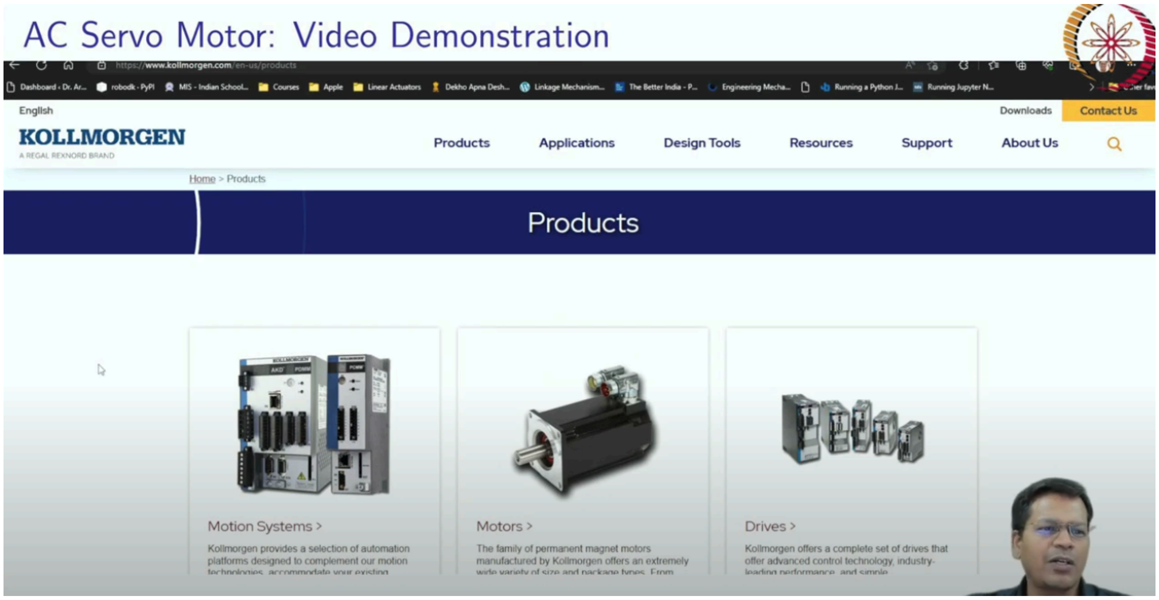
So, let's go to the working demonstration of this. So, before that, let me just show you the circuit once again. It is the same apart from this driver, which is here that is EL7211-0010. Everything else is the same. So, this is your IPC industrial PC. This is your HMI. This is your PC industrial PC, this is UPS, this is your power supply, 24 volt 120 watt. It (EK1100) is an EtherCAT coupler, so that can take in signal from here, okay? So, all the data comes from here and, later on, communicate from communicated from here to the bus system. So, from these buses, it is transmitted to other devices okay. Ultimately, it reaches your motor drive okay. So now, these are the connections which you can make. So, this is basically for the feedback. You see feedback to feedback, that means it must be some optical encoder okay and motor phase UVW three-phase wire is there, and then there is a connection for brake also, but the motor, which I have used AM8112, doesn't have the brake. So, this was not connected. Others were connected.

So, even without a brake, you know it if you stop rotating your magnetic field. Your field remains in its place with a given power, and your rotor can be halted anywhere it is okay while rotating. So, even without a brake, you can have some kind of holding torque. If that is not sufficient for safety reasons, when the power goes off, in that case, you have to apply physical brakes. So, this is the arrangement, and finally, let me run this servo motor demonstration video here.



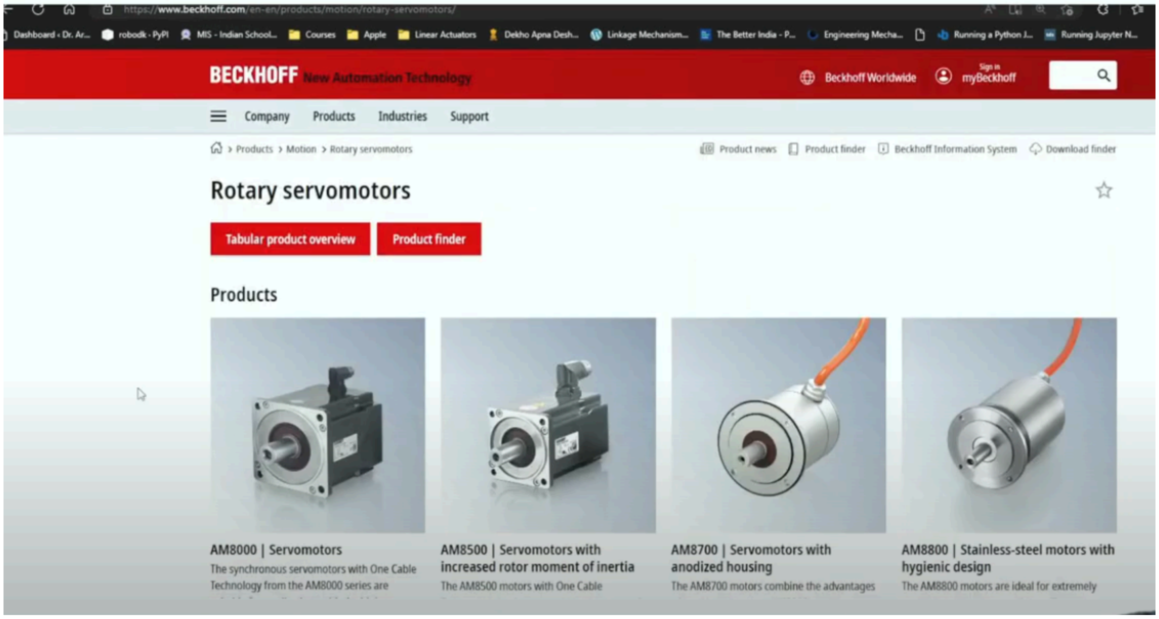
You see what I am trying to do here. So, I am continuously feeding it with a given value that is to control its step and some angle. So, it will gradually go there, and I will come back again. So, it went till 180 degrees, and it came back. Is that the position control I was doing? Again, I am coming back and remaining there first of all, and then I will go to some other angle again with a different velocity. This time, it is 360 degrees. Precisely obtained that. You can closely look at these codes that I will be sharing, okay? I will be sharing all these codes. All the resources, this TwinCAT code as well as the datasheet of these motors, the drivers, and everything will be shared as a resource for this lecture, not just this lecture. Any other lectures are also. So, with that, I would end here, at least for the servo motor.

Let me just talk about the kind of selection of these kinds of motors and how you can make the selection. So, at least for the AC servo motor. So, let us just switch to this window.



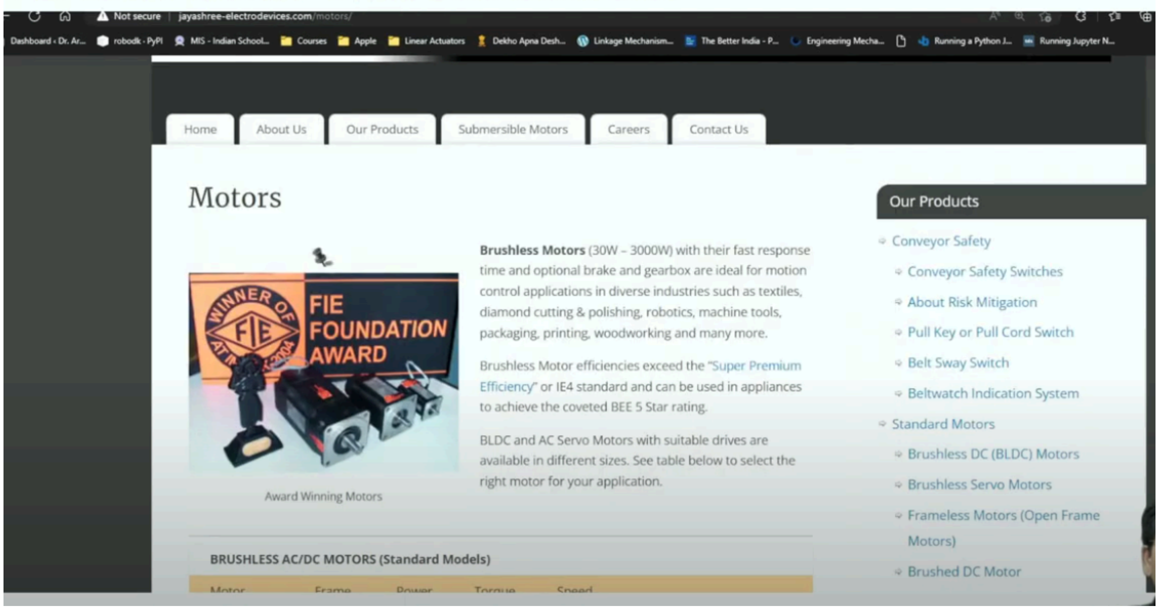
So, this is one of the products which is made by the Kollmorgen brand. So, this is a kind of motor it can make. This is a servo motor, okay? This is the motor which you want. These are the drives which it can make. Different other accessories are also there but forget about that, at least the motor and the drives in which you are interested. So, there are many other systems which are integrating the drive drives multiple drives together in a single one like this one. So there are many of these kinds which, in a compact way, integrate six accesses, and those six accesses accept different kinds of robot architecture. It can be a CNC machine. It can be a Delta robot. It can be a 6 DoF Stewart platform. It can be a standard serial robot or any robot. The kinematics are linked by different servos, so all the kinematics can be fed in here so that you just give the end effector position. This calculated motion system will calculate the motor angles and finally feed it to the six motors which are connected to this. Six or three or whatever, okay. So, this type of motion system is also there which can, which doesn't which can import kind of kinematics directly within this motion system. So, advanced drives are also there. So, this is just a driven individual. You have to take care of kinematics and the relation. This is just a motor, so Kollmorgen is one company. There are many other companies.

AC Servo Motor: Video Demonstration

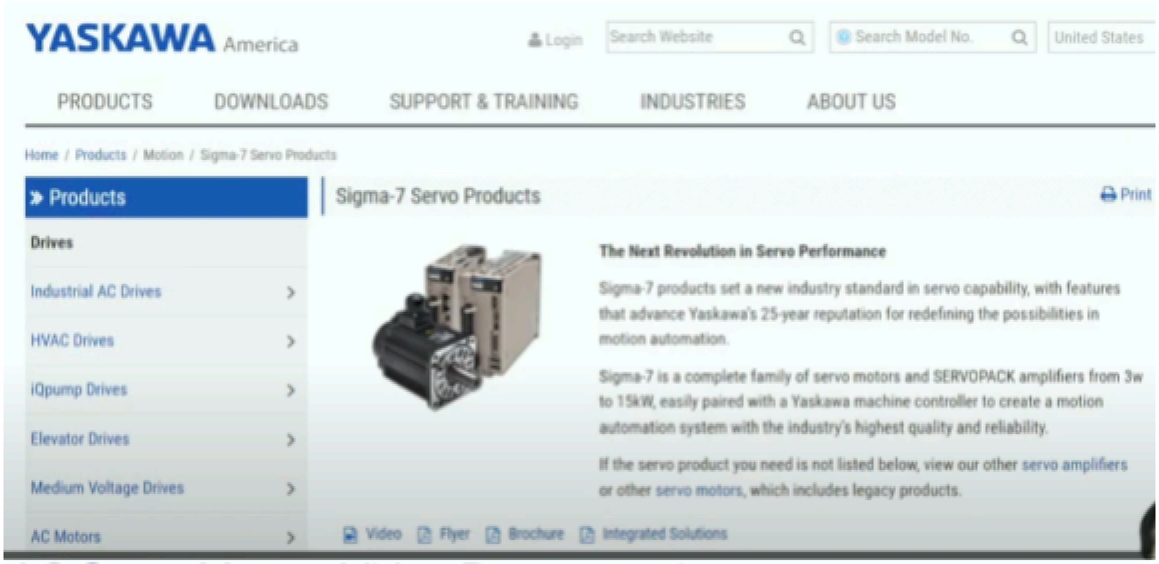


This is Beckhoff. You see, it makes different kinds of servo motors, and its drives are also. So yes, depending on your rating, your current. So, I will talk about that very much in detail after this.

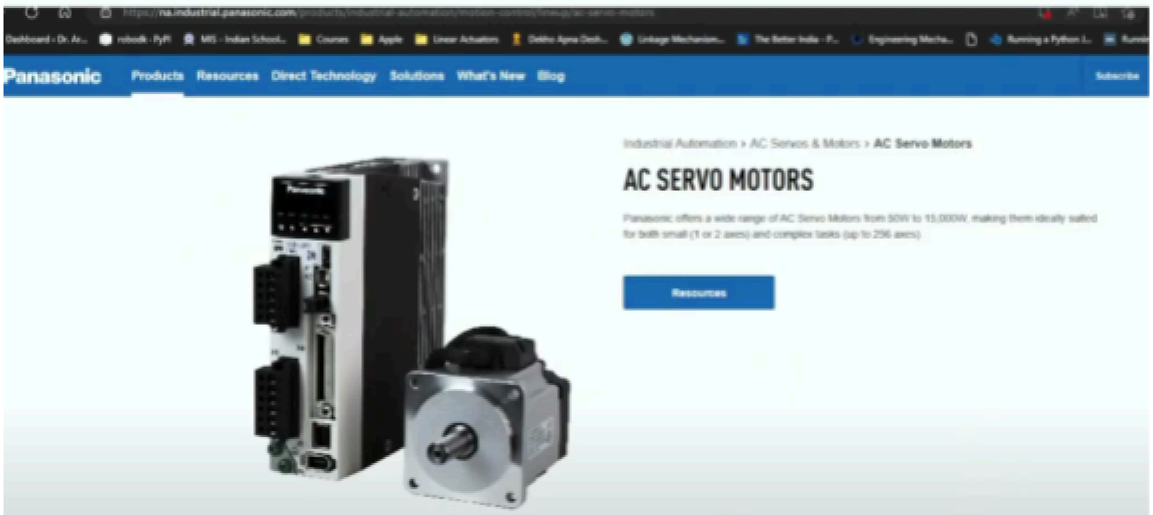
AC Servo Motor: Video Demonstration



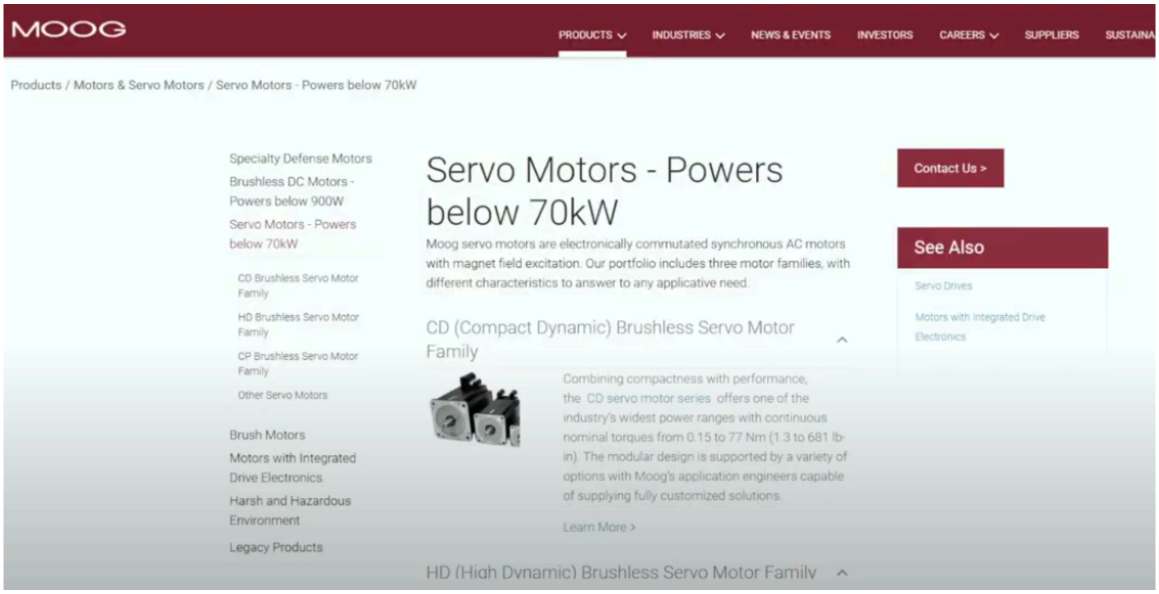
So yes, it is another one. Yet another one. So, this is a company which is in India also. It makes AC and DC brushless DC servo motors and drives.



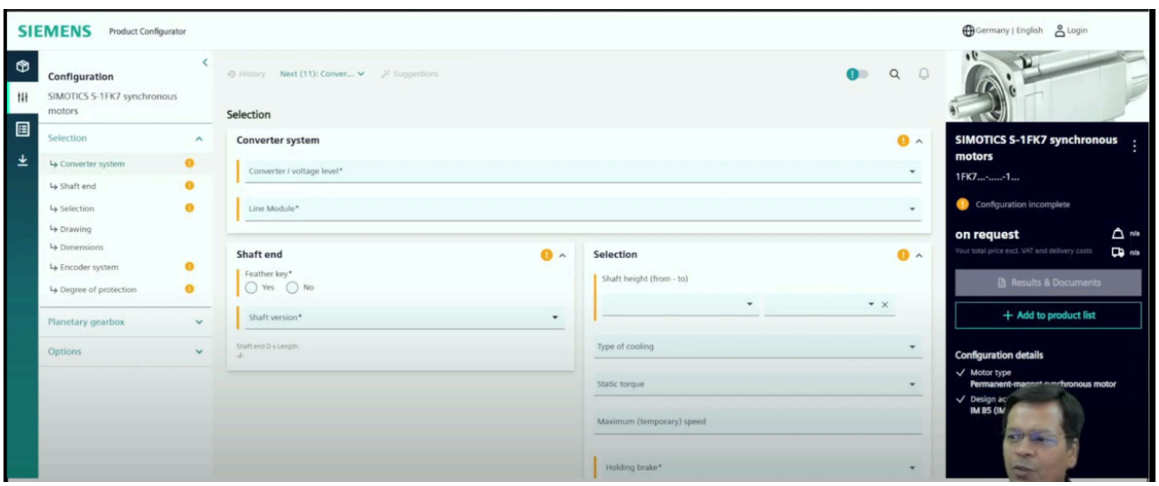
AC Servo Motor: Video Demonstration



So, this is Yaskawa. You see Yaskawa also makes motors their drives. This is Panasonic, the one which I had just now. ABB is also making it.



You have MOOG controls. They also make. You have Keyence, which is a Japanese company. Panasonic is also Japanese. So there are many, many makers you will find. So, what parameters do you select?



One of them you have to look for is sometimes even product configuration greater which is there with SIEMENS. This makes things very simple, but yes, once you look at the product specification seat, the one which I showed you just now for the controller and the robot for the motor, you can quickly compare that with your requirement, and you can select a motor whereas what is available with a particular kind of manufacturer. You can have a selection seat like this. This lets you select the converting system okay. Voltage level: what is the voltage level you want? Shaft end side: Shaft end side what kind of version do you want? It can have a flange, or it can be an angular flange. So, what should be the height, and what type of cooling? How much is the static torque that you are looking for maximum speed holding the brake or not? Dimensional thing, everything is here, you see. Encoder system if you want what sort of encoder you want, okay. So, incremental or absolutely. So, resolution, how much resolution do you want? Okay, and kind of encoder.

Different kinds of encoders can be selected which can be mounted. The type of gearbox is also here, okay. Different types of gearboxes allow you. These are the ones which are made by Siemens, but you can always have them because these motors are designed with NEMA standards. So, you can have any other make gearbox also for this reason, okay? So, you just have to take care of the maximum torque that it can handle. Otherwise, it is all the same.

Gear ratio to be fed to the is to be put to the configuration of your system. So that you get a better understanding of how much torque is getting multiplied or how much speed is getting reduced, okay? So, explosion protection if you want it. So, that also is achievable. So, for painting robots or those kinds of things, paint finish, and many manufacturer-specific options are there. So, these are a few parameters which you should look for while selecting this kind of motor okay. So, this is specific to Siemens, but there are other makes also which are there.

I'll just end here with AC servo motors. We have learnt a lot about actuators that should be sufficient at least to begin with designing your robot or maybe at least you can now understand how my robot is working. An industrial robot is working. So what are all the things that go into control of that kind of actuators, you know, right? So, what additional reading I have suggested here is data sheets. You should start looking for the data sheet. If at all you see your robot you just look at the motor model and try to browse through that kind of data sheet. Try to get hold of those data sheets and see what is the specification of that. What is the gearbox which is mounted? NEMA flange standards were. Different kinds of standards are there. So, which one is fitted here, okay? IP certification: is this enclosure safe for the kind of application I am looking for? ISO standards are being followed by this type of actuators and gearboxes. Encoders, resolvers we'll talk about this in the next module, that is, sensor. So, that is a kind of feedback angular feedback these motors were giving us to do proper control. So yes, in the next module, we'll be discussing sensors with that. Thanks a lot. Thanks a lot for covering this module. Will see you in the next class. That's all. Thank you.