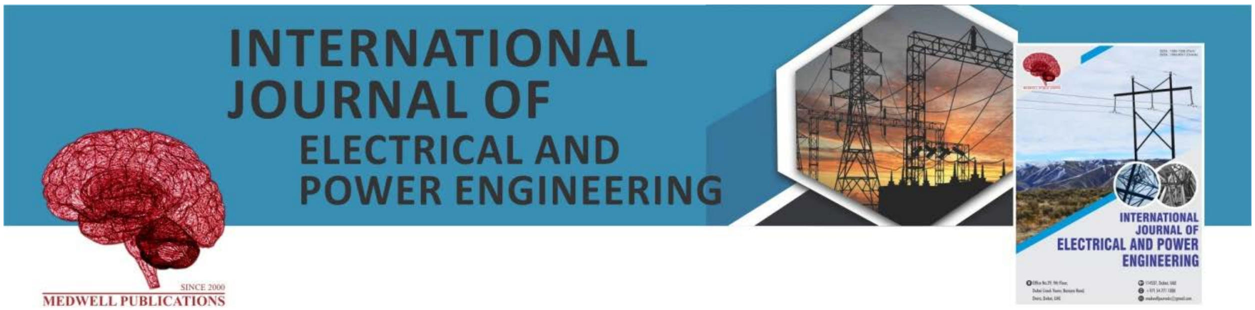

A Review of Different Motor Types and Selection of One Optimal Motor for Application in EV Industry

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Key words: Electric motors, EVs, servo, PMaSynRM

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Abstract: This scientific review report offers a synopsis of different types of electrically powered motors for the application of one of the types in an Electric Vehicle. The motors reviewed, specifically are Induction Motors, Universal Motors and Servo Motors. Great efficiency, torque, speed control, power factor and a few other parameters of electric motors are needed to be befitting the prerequisites for application in an EV. Once after thorough investigation and evaluation, the motor opted to apply (or) implement in modern-day Electric Vehicles (EV) are Servo Motors. The analysis of each motor is presented in this review article with its core principle, build (construction) and functioning of the individual machine. This review also discusses permanent magnet assisted synchronous reluctance motors servo motors (PMa-SynRM) and reducing torque pulsations in them.

INTRODUCTION

Over the centuries, electric motors have been playing a gigantic role driving the technology and facilitated almost every moving mechanism such as fans, pumps, machinery tools, appliances, power drivers, automobiles, electric watches etc. in the world. Due to current global conditions, Electric vehicles (EVs) are growing in popularity today and the world is expected to be totally automated and electrified in the near future. Technology has advanced so much such that in certain applications, such as in regenerative braking with traction motors, electric motors can be used in reverse as generators to recover energy that might otherwise be lost as heat and friction, how intriguing is that[1].

Reasons why electric motors are replacing ICEs is that electric motors are way more economical than its industrial alternative of internal combustion engine (ICE); electrical motors are generally 95% more efficient than ICEs which are 50% in efficiency at present. Motors are light, physically small, durable, less complicated and cheaper to manufacture. They are also capable of offering instant and consistent torsion at any speed, able to run on green energy and are pollution free thereby posing no harm to nature and the atmosphere.

An electric vehicle is an automobile that depends upon electricity alone. An EV does not contain an ICE like the other vehicles, instead, it uses an electric motor to drive the wheels. These vehicles are getting popular exponentially in today's era, they are a promising sustainable solution for the future of transportation.

An EV consists of an Electric Battery that supplies the electric current to the motor. Most modern electric vehicles use Lithium-ion type batteries as these batteries have a higher energy density, an Inverter, battery stores the electric current in the form of Direct Current (DC), since the motors used in the electric vehicles run on Alternating Current (AC), the inverter performs the

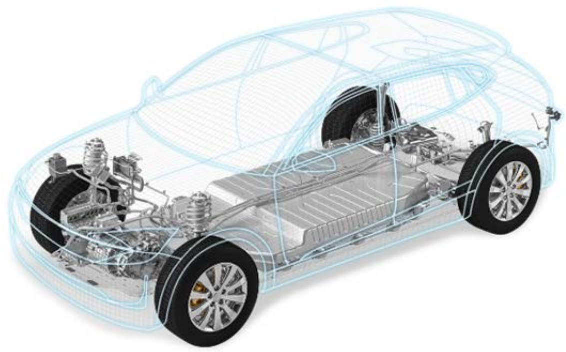

Fig. 1: Common EV powertrain[2]

function of converting DC to AC. The concept of Regenerative Braking System is too good to be not mentioned, an electric vehicle has only limited energy available, thereby, we need to save every bit of it. This system recovers the energy lost in braking, friction, heating up the vehicle and utilizes the trapped energies to charge its own batteries (Fig. 1).

In this review different types of motors are studied, specifically, induction motors, universal motors and servo motors. These motors have a simple build (construction), a rotating part, namely, a rotor and a stationary part, known as stator. All these motors were tested and thoroughly evaluated to conclude the perfect motor for EVs (Electric Vehicle) applications[2]. Pros and details of the opted motor have been mentioned conscientiously in this review. The ongoing R&D is primarily based on the PMa-SynRM engine, that can be proved as an ideal engine and holds the ability to be comprehensively designed to fulfill all necessary aspects.

REVIEW OF MOTORS

Induction motors

Principle: An Induction Motor works on the principle of electromagnetic induction defined by Faraday's law of induction. The electromagnetic induction is a phenomenon in which the emf (electromotive force) induces current across the electrical conductor when placed in a rotating magnetic field. The alternating current in the stator windings createa rotating magnetic flux which cuts the conductors of the rotor. This motor has no direct wiring/connections to the rotor[3]

Construction and mechanism: A three phase Induction motor primarily consists of 2 components referred to as Stator and Rotor. a rotating part, namely, a rotor and a stationary part, known as stator. The development of the stators are of like the three-phase synchronous motor, whereas the construction of rotor is different for the different motors (Fig. 2).

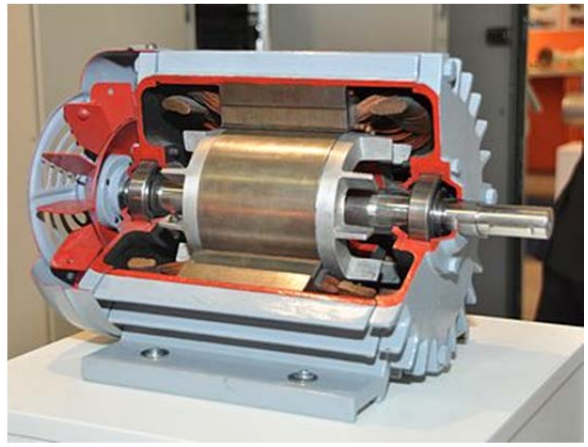

Fig. 2: Cutaway view through Induction motor[1]

When a three-phase supply is given to the stator, a rotating magnetic field is produced on it. The polarities of the magnetic field vary thus the change in polarities makes the magnetic field rotate the rotor.

Universal motors

Principle: A universal motor's working principle is like a DC series generator. When current flows into field winding, an electric field is generated while the current still emanates from the armature conductors. Hence when a current conductor is put in an electric field, a mechanical force is exerted thus moving the rotor[4].

Construction and mechanism: The field coils are wound around the poles of the field. However, the entire magnetic path, the stator field circuit as well as the armature are laminated. Layering is important to reduce eddy currents. The rotating armature has a coiled shape with straight or twisted slots and a twisted brush on it.AC switching is worse than DC switching. Because of the current caused by the armature coils[4] (Fig. 3).

Servo motors: Servo motors are a contained electrical device, which rotate machine parts with great precision and high efficiency. Shaft of this motor has the ability to be moved to a particular angle, position with controlled speed, unlike any normal motor. The servo motor has a normal motor and uses a sensor for positioning feedback.

There are two types of Servo Motors, AC and DC, further classified into Brushed or Brushless. Although both AC and DC motors are used in servo systems, AC motors can handle higher currents and are more commonly used in robots, production lines and many other industrial factories etc., where continuous repetitions of processes and precision is required. Brushed

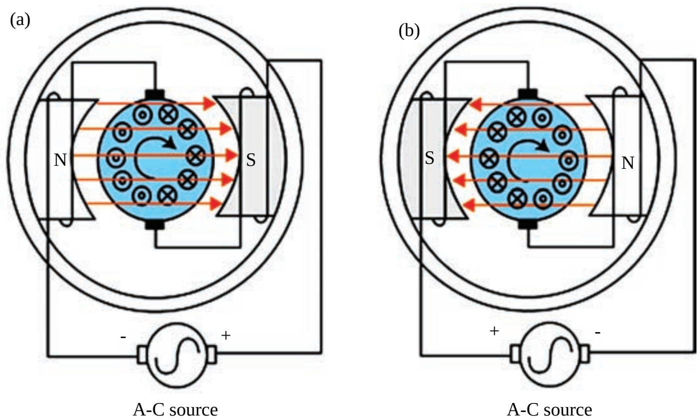

Fig. 3: Working of a universal motor[4]

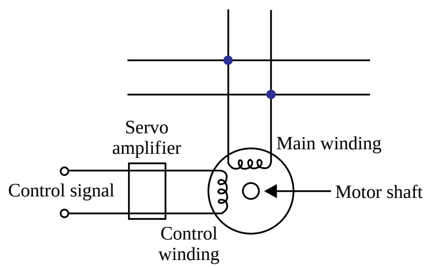

Fig. 4: AC servo motor circuit[7]

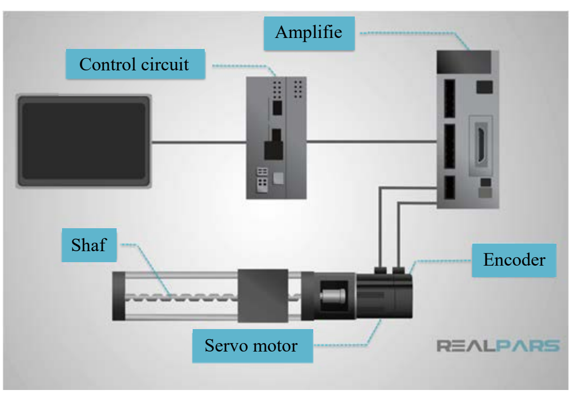

Fig. 5: Motion control system of a servo motor[8]

motors are cheaper to acquire (less expensive) and easier to use, while brushless models are more reliable, less noisy and are more efficient (Fig. 4).

Principle: A servo motor works on the principle of PWM (Pulse width modulation), that means its angle of rotation can be controlled by the width of pulse fed to its control PIN. Basically the servo motor consists of a AC/DC motor which is controlled by a variable resistor (potentiometer) and some gears[5].

Construction and mechanism: Servos are generally controlled by sending a variable-width electrical pulse, or Pulse-Width Modulation (PWM), through a control cable. There is a minimum pulse, a maximum pulse. The 0 position is defined as the position where the servo holds the potential to move in clockwise and counterclockwise direction equally. The PWM sent to the motor determines the angles of rotation of the shaft, totally depending on the period of the pulse fed; the therefore rotating the rotor to the desired position (Fig. 5).

REVIEW OF OPTED MOTOR

After studying deeply, the principles and mechanisms of multiple motors showing in Fig. 6 and 7, the most suitable motor found to be implemented in Electric Vehicles (EVs) is a Servo motor.

What is a servo motor?: If the rotor turns at the same speed as the Rotating Magnetic Field (RMF) generated by the stator, it is called a synchronous servomotor. The synchronous servo motor needs double excitation, the stator needs to be supplied with alternating current and dc is supplied to the rotor or the rotor could consist of a permanent magnet which could provide a permanent or fixed magnetic field. With the help of an initial rotation, the rotor magnetically locks with the stator and thus the motor begins to rotate at the same speed as the RMF. Servo motors have the ability to run at constant speed regardless of the load acting on them.

These motors are typically high in efficiency and used in high precision applications. Synchronous Speed, the speed at which the rotating magnetic field in the stator, created by providing a three-phase power supply, spins. When the rotor rotates at this synchronous speed, these types of motors are called synchronous

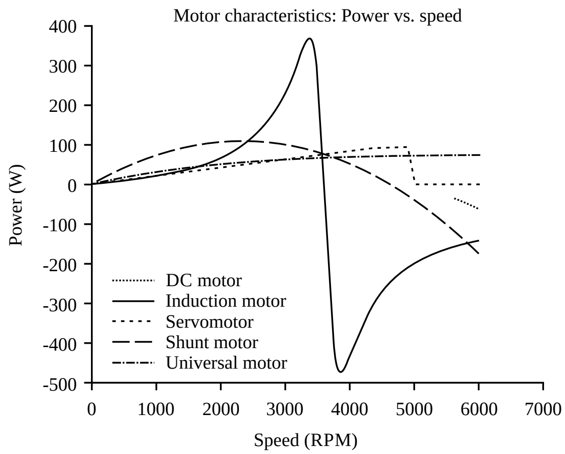

Fig. 6: Motor characteristics-power VS speed curve[12]

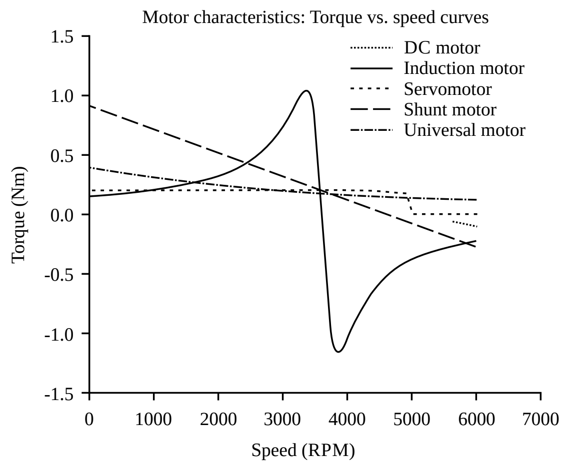

Fig. 7: Motor characteristics-torque VS speed curv[12]

Fig. 8: Construction of servo motor[9]

servomotors. The rotor is either excited by a DC power supply or consists of a permanent magnet that creates a permanent magnetic field. Assuming the rotor is initially rotated in the direction of the RMF (rotating magnetic field), then the opposite poles of any field are magnetically attracted and locked so that the rotor begins to move at synchronous speed. In a special case, they are called synchronous capacitors, since they are used to improve the power factor in any electrical network, which is done by changing the field current or excitation (Fig. 8).

In this part of the review, we will be explaining the motor construction, principles, equivalent circuit, winding arrangement, performance characteristics, advantages and disadvantages of a Servo Motor.

CONSTRUCTION

The servo motor has a rotation sensor (encoder) hooked up at the back of the motor shaft to locate the location and pace of the rotpositioning operation. A servo includes the following subsequent parts:

- **Stator:** A rotating magnetic field is generated to generate torque
- **Winding:** Current flows within side the winding and creates a rotating magnetic field
- **Ball bearing:** Decreases friction among the shaft and rotor
- **Shaft:** This component transmits the power of the engine
- **Rotor:** It is the movable part of the motor attached to the shaft
- **Encoder:** The encoder monitors and verifies revolution and angle
- Motor and Encoding Cables

Working principle: A servo motor works on the principle of PWM (Pulse width modulation), that means its angle of rotation can be controlled by the width of pulse fed to its control PIN. Basically the servo motor consists of a AC/DC motor which is controlled by a variable resistor (potentiometer) and some gears[5].

Equivalent circuit and winding arrangement: There are only two types of motor winding, namely, rotor winding and stator winding. The type of winding found in servo motor is main winding in stator and the auxilliary winding in rotor using the damper winding method, which is a short-circuited squirrel-cage winding placed in the pole faces and around the pole shoes of synchronous machines, the currents induced in the winding by the periodic variations in synchronous speed having the effect of a damper (Fig. 9).

Two kinds of the windings exists:

- Wound-type
- Squirrel cage type

Squirrel cage rotors are preferred over other wound-types due to cheaper cost, lesser maintenance requirements and higher strength.

Table 1: Advantages and disadvantages of servo motors[13]

Servo motor advantages	Servo motor disadvantages
Servo motor provides high speed and high torque	Servo motor lags behind the given pulses for small time-period (high-frequency) tasks making precision control difficult and complicated.
Servo Motor can work with the heavy and bulky loads	During operation, vibration causes lack of efficiency at times.
Smooth speed control and frequent switch makes operations precise and simple	Servo-motors are expensive compared to other types of motors available in the market
It's compact size makes it fit for almost every application	Repairing cost for a damaged servo motor is high

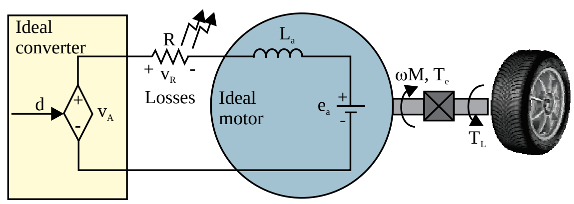

Fig. 9: Equivalent circuit of a servo motor[10]

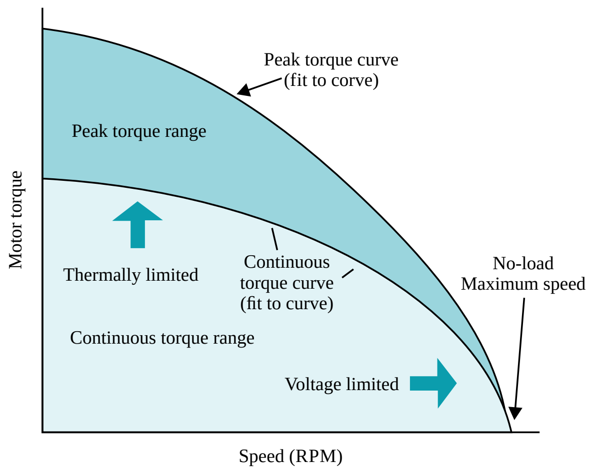

Fig. 10: Servo motors in peak and continuous torque ranges[11]

Performance characteristics: The Root Mean Square (RMS) torque of the motor is used when assessing whether an application is within the continuous duty zone. RMS torque takes into account the variable torque requirements throughout the motor's working cycle, including acceleration, constant speed, deceleration and dwell time. - as well as the time period in which each torque level should occur. The purpose of the RMS is to determine the level of torque to avoid circumstances that would result in the motor heating.

The ambient temperature also influences how quickly the motor reaches its thermal limit and thus its continuous torque. If the motor is operated in an area with an ambient temperature higher than that specified by the manufacturer, the servomotor torque curve should be adjusted (reduced) accordingly. Conversely, if the ambient temperature around the motor is significantly lower than the ambient temperature specified by the manufacturer, the motor's continuous torque rating may increase (Fig. 10).

Advantages and disadvantages of servo motor: Servo Motor has an endless list of applications in real life, it can be used in various different fields[6]. Some applications of Servo Motors can be found as (Table 1).

- Electronic tools for precision cutting, drilling etc.
- Automation Technology
- Robotics Technology
- Drones and Autonomous Propelling Systems
- Electronic Devices such are cinematographic lights and camera systems etc.
- Other technologies such as IoT devices, AI Products, Outer-Space Satellite Maintenance etc.
- Servo Motors can also be used in hi-technology machinery such as 3D Printers, CNC mills, Hydraulics, Automated manufacturing units etc.

APPLICATION: IMPLEMENTATION IN AN ELECTRIC VEHICLE

High efficiency, torque, power density and constant power: speed ratio are the most essential elements for application in an electric vehicle. Losses such as eddy current loss, ohmic loss, power loss (heat) and hysteresis loss contribute hugely in causing inefficiency in motors. Other advantages are the synchronous rotation speed, the possibility of rotation control, high power factor and better efficiency. In sensor-free control techniques, the values at the terminal that includes voltages and stator current are used to extract the speed of the rotor. These sensor-free techniques provide a compact, strong and a robust motor, which are able to function without loss in different temperature or weather conditions and great drive performance. Therefore, Servo Motors can be used as the driving motors in EVs based on its advantages, like favourable power density, high efficiency and smooth controls. Hence, implementation of Servo Motors in Electric Vehicles should not be neglected as Servo Motors can provide high torque, high efficiency at low armature currents, compared to other motors available in the market (Fig. 6 and 7).

The motors which are hybrid in nature, hybridised with Servo and Induction motors, namely IPM and SynRM motors may be used in today’s EVs due to their vitality whose joined benefits nullifies the disadvantages. These motors are super-efficient, compact and greatly reliable regardless of low or high operating speed.

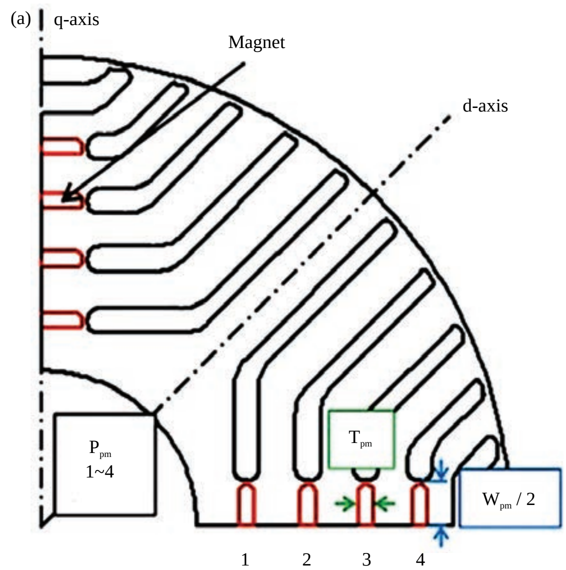

Fig. 11(a-b): Performance analysis of synchronous reluctance motors in (a) Prius IPM and (b) PMaSynRM[15]

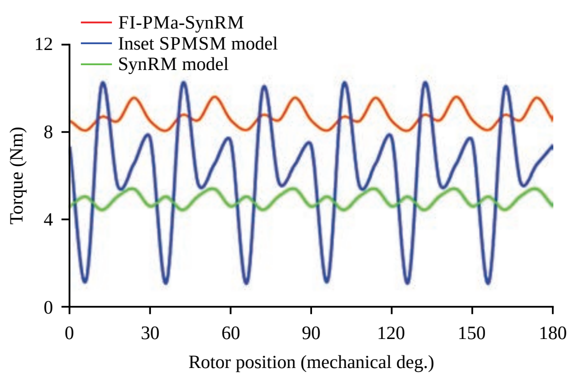

Fig. 12: Torque: Rotor position curve of PMaSynRM motor[16]

ONGOING R&D

Currently, the PMaSynRM engine (motor) for EVs is gaining a lot of attention and research is on for further optimization aiming at increasing its efficiency and strengths. The Permanent Magnet (PM) assisted synchronous reluctance motor paves the way for a better economical path due to less magnetic composition and magnetic flux binding or linkage (Fig. 11).

The electric motor IPMSynRM is currently being used by the auto-maker Tesla's Tesla Model 3. The motor uses a 6-pole design that offers increased torque and power. A hybrid electric car, by auto-make Toyota, Toyota Prius, uses the IPMSynRM electric motor. It uses two IPMSynRM motors, one for drive wheel and another for power generation (electricity). The motors in Toyota Prius contain large magnets, whereas the motors in Tesla Model 3 has segmented the magnets in 4 parts. The segmentation of magnets helps to reduce the eddy currents in the magnets, preventing overheating thereby decreasing the chances of demagnetization and acts as aiding function by keeping the motor cooler. The only difference between the motors used for Tesla 3 and Toyota Prius lies in the magnets used[14] (Fig. 12).

CONCLUSION

This literature review offered a synopsis of different types of electrically powered motors for the application of one of the types in an Electric Vehicle. The motors reviewed, specifically were Induction Motors, Universal Motors and Servo Motors. Great efficiency, torque, speed control, power factor and a few other parameters of electric motors are needed to be befitting the prerequisites for application in an EV. Post long research hours and investigation it can be concluded that, Servo Motor (Synchronous) is the most favourable motors due its physical and electrical properties, by providing high torque, precision movement and being highly efficient. Current R&D proved that hybrid SynRM motors that use both magnetic and reluctant properties prove to be the most productive motors for application in a modern-day Electric Vehicle (EV) resulting in advanced, hi-tech and powerful motor build. These motors are already in use by giant auto-makers Toyota and Tesla, helping in their production of Hybrid and Electrics cars, respectively. Adjustments such as lamination of rotors to prevent eddy loss etc can improvise the functionality and efficiency of the motor, making it an excellent alternative to the motors currently in use in the Electric Vehicle industry.

REFERENCES

1. Wikipedia, the free encyclopedia, 2022. Electric motor. https://en.wikipedia.org/wiki/Electric_motor
2. Allegro Micro., 2022. Hybrid and electric vehicle systems. https://www.allegromicro.com/ja-jp/applications/automotive/hybrid-electric-48v
3. University Teaching Departments (UTDs and UIT) 2022. Rajiv gandhi proudyogiki. https://www.rgpv.ac.in/
4. Daware, K., 2022. Universal Motor - Construction, Working And Characteristics. https://www.electricaleasy.com/2014/02/universal-motor-construction-working.html#:~:text=Construction%20of%20Universal%20motor&text=It%20consists%20of%20a%20stator,induce%20while%20operating%20on%20AC.
5. Jameco, 2022. How servo motors work servo motors: High in efficiency and power. https://www.jameco.com/Jameco/workshop/Howitworks/how-servo-motors-work.html
6. Circuit digest, 2015. What is a servo motor? - Understanding the basics of servo motor working. https://circuitdigest.com/article/servo-motor-working-and-basics
7. Workbook, V., 2022. AC servo motor - working principle, circuit diagram, construction, characteristics & applications. https://electricalworkbook.com/ac-servo-motor/
8. RealPars., 2022. What is a servo motor and how it works? https://realpars.com/servo-motor/
9. Overview, S., 2022. Servo motor overview structure of servo motors. https://www.orientalmotor.com/servo-motors/technology/servo-motor-overview.html
10. Yodwong, B., P. Thounthong, S. Sikkabut, P. Mungporn and C. Pukdeboon *et al.,* 2016. State-observers for differential flatness model based-control of high-performance DC servomotor drives. 2016 19th International Conference on Electrical Machines and Systems (ICEMS). 2016.
11. Collins, D., 2018. Servo motor torque curves: What you need to know. https://www.motioncontroltips.com/servo-motor-torque-curve/
12. Mathworks, 2022. Motor torque-speed curves. https://www.mathworks.com/help/physmod/sps/ug/motor-torque-speed-curves.html
13. Rubo in, 2020. What is Servo Motor – Advantages, Disadvantages Applications. https://robu.in/what-is-servo-motor/
14. Bolognani, S., L. Ortombina, F. Tinazzi and M. Zigliotto, 2017. Model sensitivity of fundamental-frequency-based position estimators for sensorless pm and reluctance synchronous motor drives. IEEE Trans. Ind. Electron., 65: 77-85.
15. Duc-Kien, N. and Min-F. Hsieh, 2019. Performance analysis of synchronous reluctance motor with limited amount of permanent magnet. Energies, 10.3390/en12183504
16. Hsieh, M.F., D.K. Ngo and N.G.M. Thao, 2022. Flux intensifying feature of permanent magnet assisted synchronous reluctance motor with high torque density. Electronics 10.3390/electronics11030397