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A Review on Hybrid Electric Vehicle Powertrains

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Abstract: There is a grave problem of air pollution in India. In 2019, 21 of the 30 most polluted cities in the world were from India. A study done in 2016 shows that at least 14 million people in India breathe air that is ten times over the WHO safe limit. 27% of pollution is spread by vehicles. There are more than when it comes to e-mobility, it is not just about electric vehicles. Hybrid vehicles are being seen as a temporary way to fill the gap between conventional vehicles and EVs. since EV charging infrastructure is still not created in India where, hybrid vehicles can make a difference in the short to medium term. There is dire need to adopt HEVs in order to prevent an immense increase in climate change and limited natural resources on our planet. This paper is focused on the review of the classification of the HEV powertrains based on hybrid vehicle configurations. The advantages and disadvantages of serial, parallel, or power-split/series-parallel hybrids are also discussed.
Keywords: Hybrid Electric Vehicle, Powertrain.

I. INTRODUCTION

Since there are some major disadvantages in EV such as low energy density of the battery, low range, ponderous refueling, high cost. Consumers are looking for an alternate of ICE. Until the solution of the EV is established researchers are looking toward HEV as a substitute to extinct the ICE. Hybrid Electric Vehicles are becoming more adapting to nature in the transportation sector in recent times. The present trend shows suggest this mode of transport is going to replace an Internal combustion engine (ICE) vehicle in the near future. The efficiency of an electric motor is prodigious than ICE. Not only do HEVs provide better fuel economy but also lower emissions that satisfy environmental measures, they also reduces the effect of rising fuel prices on consumers. HEVs merges the drive powers of an internal combustion engine and an electrical machine. The main components of HEV are motor, bidirectional convertor, ICE, energy storage system (battery and fuel tank), and control board. These are different combinations of powertrain available in market, series/extended range HEV, parallel/plug-in HV, series-parallel hybrid. The key difference between these hybrid systems is that in the series hybrid system IC engine is not directly linked to the wheels, on the contrary, it is directly coupled in the parallel hybrid system. The overall system efficiency in the series hybrid system must be lower than that in the parallel hybrid system because of double- conversion of engine mechanical energy to electrical and then back to mechanical energy. Despite this complication, it is assumed that the series hybrid system will give a better fuel economy because the ICE can run between its max efficiency range all the time and is independent of the load on the vehicle.

II. CLASSIFICATION OF POWERTRAINS

A. Conventional Powertrain

The mechanism by which power is generated and transmitted to the road is known as powertrain. (Collins English Dictionary)**.** Let us consider the commonly used rear-wheel drive system used in a conventional powertrain. As shown in fig (1) it is a primitive way of power transmission where fuel is ignited in the engine. Which converts linear motion into rotation, further power is transmitted to clutch which works as a switch which controls the torque transmission. Gearbox in general used in a manual transmission allows the variation in output. While torque convertor is used automatic transmission. torque proceed from differential to the wheel. Since there is no battery pack in the vehicle. Regenerative braking and energy storage is not applicable in conventional vehicles.

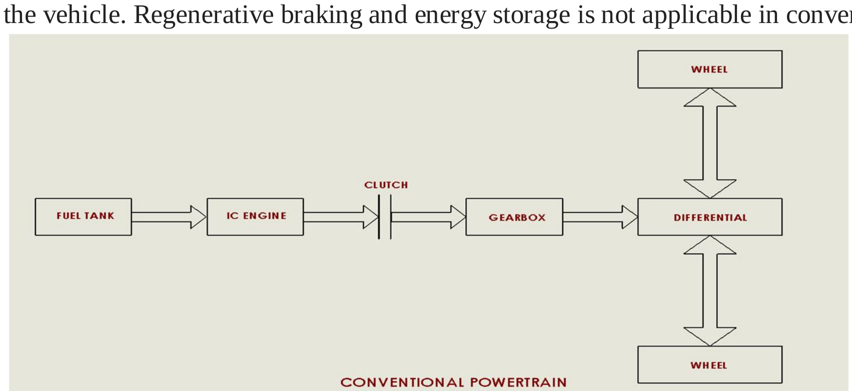

Fig 1 Conventional Powertrain

B. Hybrid Electric Vehicles (HEV)

A hybrid electric vehicle is a combination of the electric propulsion systems and conventional propulsion system. The electric powertrain is installed to have better performance and fuel economy than the conventional powertrain. A hybrid-electric vehicle produces scarcely any tailpipe emissions than an equivalently sized gasoline car since the hybrid's gasoline engine is usually minor than that of a gasoline-powered vehicle. If the engine is not used to propel the car directly, it can be geared to run at maximum efficiency, further improving fuel economy.[6] The flow of energy in a primitive HEV is shown in figure (2&3). During the ignition of the vehicle, the heat engine (ICE) may run the motor as a generator to extract some power and store it in the battery pack. While overtaking other vehicles high acceleration is required which is fulfilled by concurrently working of the ICE and motor. During braking the motor works as a generator to charge the battery by regenerative braking.

Power Flow at Different Modes

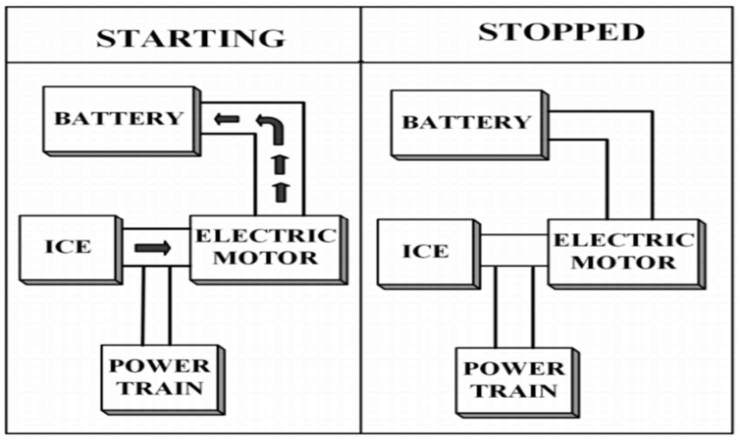

Fig 2 shows energy flow at start, stop

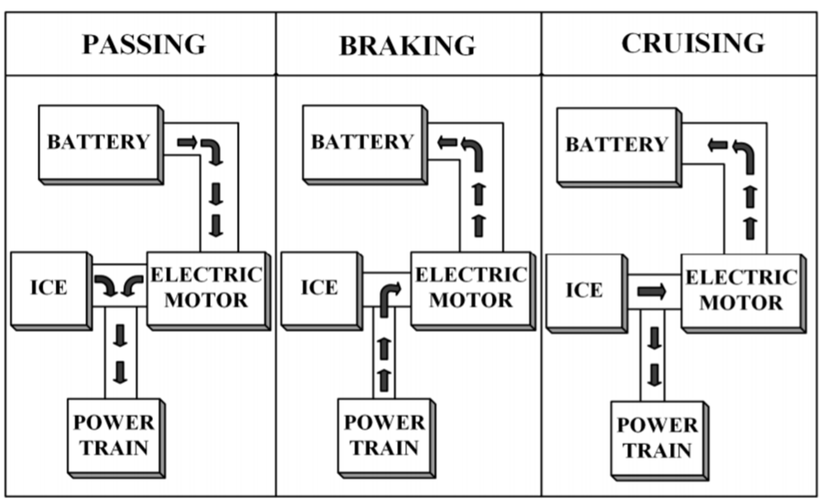

Fig 3 shows energy flow at passing, braking, cruising.

1) *Parallel Hybrids:* The Prime difference between parallel and series hybrid systems is that the internal combustion engine is not coupled directly to the wheels in the series hybrid system, but it is directly coupled in the parallel hybrid system. In the current situation, most of the produced hybrid vehicles have a parallel structure. An ICE and an electric motor are coupled. In short, in a parallel system, there is an unmediated connection between wheels and the power unit. Batteries can charge while ICE is in primary mode. Simultaneously more power can be delivered from both sources. While braking electric motor will work as a generator. Regenerative braking stores the power developed in batteries. There are several modes of a drive to minimize the loss of energy. The following are the modes, combustion only, electric only, electric/hybrid, and regenerative braking. An electronic control unit (ECU) is installed which monitors the data input from various parts of the vehicle.

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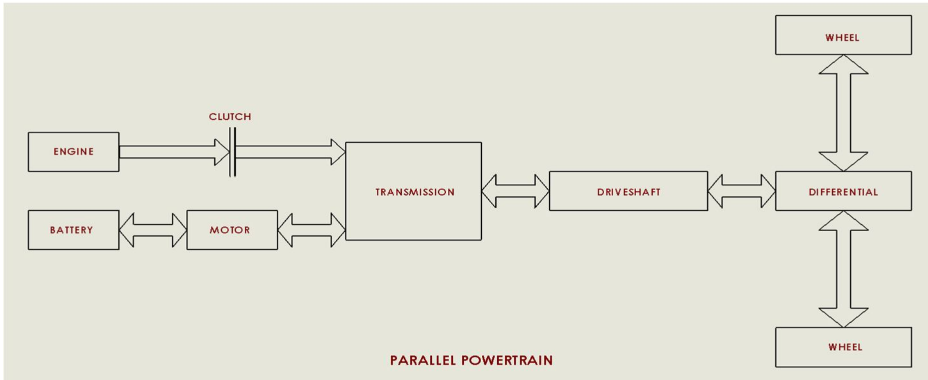

Fig 4. Parallel Powertrain

a) Advantages & Disadvantages

The crucial advantages of the parallel hybrid powertrain are:

- Due to the torque supplied directly to the wheels by the engine and motor power loss is less because there is no energy conversion to the driven.
- Since there is no need of the generator and traction motor vehicle is compact.
- Has a similar design compared to the conventional powertrain.
- Very low emission.
- It is efficient and consumes less fuel compared to a series hybrid.

b) Disadvantage as follows

- Mechanical coupling between the engine and the driven wheels, thus the engine working points cannot be fixed in a narrow speed region.
- To maintain efficiency high voltage is required.
- Typical structure and control. Due to its compact characteristics, the parallel powertrain is used in small vehicles.

2) *Series Hybrids:* Series powertrain has the basic hybrid configuration. By adding an engine in an authentic battery-powered electric vehicle, series hybrid vehicles are invented. In a series hybrid, the engine is coupled to the generator/convertor hence the only source of power providing to the wheel is motor. Depending on the power consumption the motor receives electric power from the battery pack or from a generator which is driven by an IC engine. The battery is recharged by regenerative braking and generator. The electronic control unit (ECU) controls the flow of current from the battery to the wheel. Basically, an engine is introduced to fulfill the excess power required to the battery pack. The engine is smaller in series hybrid equal to the power demand, but the battery is more powerful than the series hybrid. These requirements like larger battery, generator, and engine make series hybrids more costly than parallel [7]. At idle condition or in traffic conventional engines are inefficient but the series hybrids conduct well in traffic or in idle.

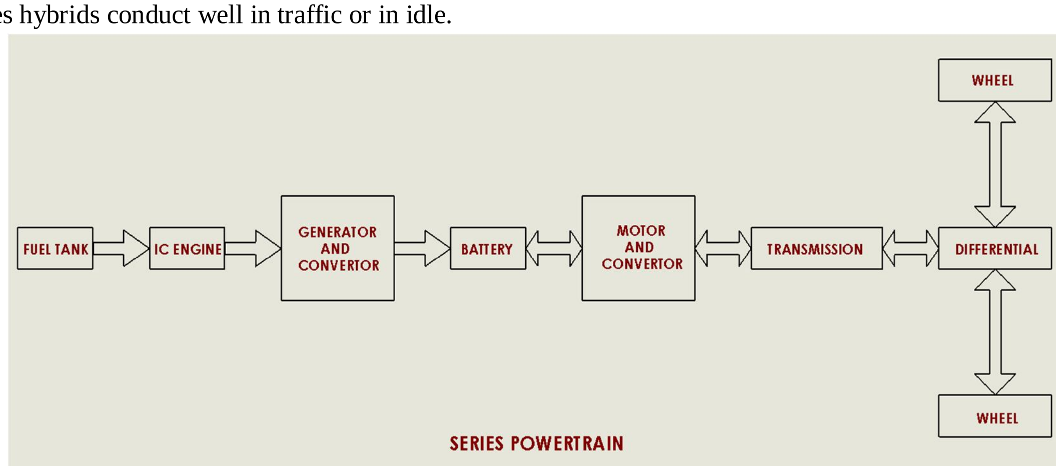

Fig 5 Series Powertrain

a) Advantages & Disadvantages

The noticeable advantages of series hybrid drivetrains are:

- IC engine can be operated at its very narrow optimal region due to differentiated mechanical output of the engine to the wheels.
- The use of electric motor has prevented the use of complex multi-gear transmission in the series hybrid powertrain.
- Construction is very simple as the whole system is interconnected by electrical wires.

Nevertheless, disadvantages are always there such as 1) since the energy alteration is twice caused more energy waste i.e mechanical to electrical from the engine to generator then mechanical again from the motor to the differential. 2)torque provided to the wheels only by the traction motor hence substantial traction motor required.

3) *Power-split or Series-parallel Hybrid:* As the name suggests power-split hybrid the power from the engine is splitted into two parts; one part is transmitted to the drivetrain and the other to the generator. The generator has a dual function when generator speed is positive, the generator operates in motoring mode and adds the power to the driven wheels. That is how the engine speed can be adjusted to its optimal region by controlling the generator/ motor speed. When the generator speed is negative, the generator operates in generating mode. In this technique, the engine has adhered to the stator, and the rotor is connected to the drivetrain wheel through gears. The traction motor is also a torque provider, which adds torque to the drive wheels.

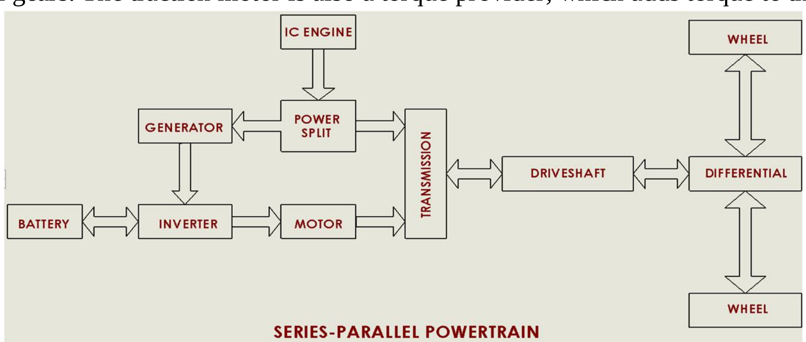

Fig.6 Series Parallel Powertrain

a) Advantages & Disadvantages

- A Combination of Series and parallel hybrids blends the advantages and disadvantages of both hybrids. By merging the two designs, the engine can drive the wheels directly similar to the parallel hybrids, and be efficiently disconnected, with only the electric motor providing power similar to the series hybrid. In different driving modes like only-electric and only-gasoline, the engine operates at near ideal efficiency. However, at lower speeds, it operates as a series vehicle, but at high speeds, the engine work as primary source and energy loss is minimized, since the series drivetrain is less efficient at high speed.
- The biggest disadvantage this system has is its higher costs than a parallel hybrid since it requires a generator, a larger battery pack, and more computing power to control the dual system. However, it also requires an additional electric machine and a planetary unit, which makes the drivetrain complicated to some extent.

III. FEATURES OF DIFFERENT HEV

Features Type	Start-Stop System	Charge-drain mode	Regenerative braking	Rechargeable
Plug-in hybrid	Yes	Yes	Yes	Yes
Micro hybrid	Yes	No	No	No
Mild hybrid	Yes	No	Yes	No
Full hybrid	Yes	Yes	Yes	No

IV. SALES OF HEV WORLDWIDE

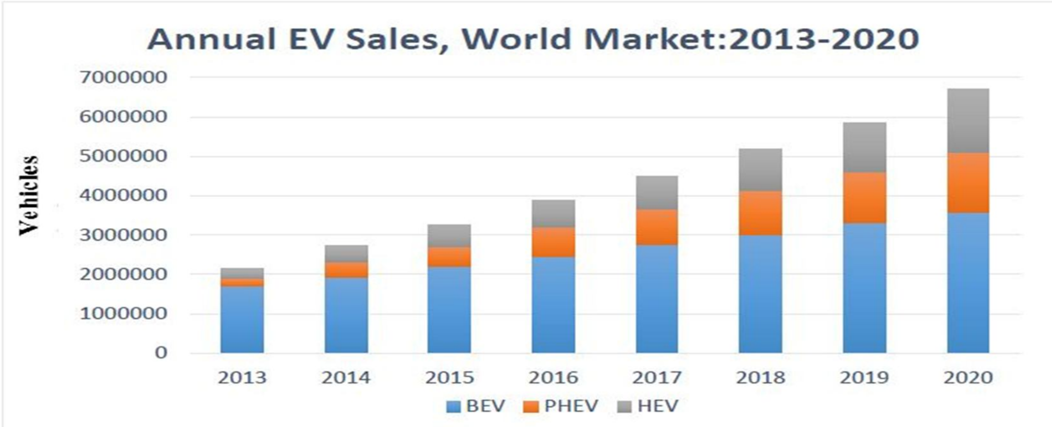

Fig. 7. Graph shows the sales of PHEV, BEV and HEV globally.

Sr No	Model	Engine	Electric motor	Transmission	Dimension in Inches Height/Width/Length	Range
1	Toyota camry hybrid LE 2020	2.5-Liter Dynamic Force 4-Cylinder DOHC VVT-I; 202 hp @ 6600 rpm;	650V ElectricMotor118HP(88KW) Torque 202N.m	e-CVT	56.9/72.4/192.1	EPA= 52mpg
2	Toyota prius prime plug in hybrid 2020	1.8-Liter 4-cylinder Aluminum DOHC VVT-I; Torque=142 Nm @ 3600 rpm 95 hp 71KW @ 5200 rpm	Permanent magnet AC synchronous motor 600V 34.5Kw	e-CVT	57.9/69.3/182.9	EPA= 640 mi
3	2020 Fusion Hybrid SE(PHEV Model)	2.0L Atkinson-Cycle I-4 Plug-In Hybrid Engine 141hp @ 6,000 Torque 95N.m @ 4,000	88 kW Permanent Magnet AC Synchronous Motor	e-CVT	58.22/72.9/ 191.8	EPA= 103MPGe
4	Corolla Hybrid LE 2020	1.8-Liter 4-Cylinder Aluminum DOHC 16-Valve (VVT-i); 121 hp @ 5200 rpm, Torque=142N.m @ 3600 rpm	600VPermanent magnet AC synchronous motor163N.m 84Hp(63KW)	e-CVT	56.5/70.1/182.5	EPA = 52mpg
5	Toyota Avalon Hybrid 2020 XLE	2.5-Liter Dynamic Force 4-Cylinder DOHC 16-Valve VVT-iE, VVT-I 76 hp @ 5700 rpm; Torque=120N.m @ 3600-5200 rpm	650V electric motor 118 HP(88 kW) 149 lb.-ft.(202 N.m)	e-CVT	56.5/72.8/195.9	EPA = 44MPG
6	Ford escape SE Sport hybrid 2020	Hybrid 2.5L iVCT Atkinson-Cycle I-4 engine 165hp@ 6,250 Torque=210N.m @ 4,000	Electric motor 118hp(88KW)	e-CVT	66.1/85.6/180.5	EPA 40mpg
7	Honda Clarity Plug in Hybrid2020	1.5L DOHC VTEC® 4-cylinder engine 31hp(24KW) Torque NA	AC Permanent-Magnet Synchronous Electric Motor 181hp (136KW)	e-CVT	58.2/73.9/192.7	EPA 42mpg
8	Accord Hybrid 2020	2.0-litre, 16-valve, Atkinson cycle DOHC, i-VTEC® 4-cylinder 143hp @ 6200 Torque=194N.m @ 6200	181hp @ 5000-6000 315N.m@ 0-2000	1-speed CVT	57/84/192	EPA 48mpg
9	Chevrolet Malibu RS 2020	4-cylinder dual overhead cam design with(VVT) 160 hp @ 5700 rpm 184 lb-ft of torque @ 2500-3000 rpm	Electric motor 90hp(67.5KW)	CVT	57.9/73/194	EPA 32mpg

Table 1. Various models of Hybrid Vehicles

V. CONCLUSION

This paper systematically reviews the current hybrid vehicle powertrains. As for the configuration, series, parallel, and series–parallel are the most commonly used configuration. For the advantages and disadvantages, a series hybrid configuration is commonly used in heavy-duty vehicles, military vehicles, and buses. On the other side, parallel and series–parallel is largely used in small automobiles, such as passenger cars. The series hybrid system lags from the parallel system because of the dual conversion of engine mechanical energy to electrical and vice versa. Nevertheless, the charge-sustaining quality of the series hybrid system exposes that the energy drained from the battery significantly reduces over the drive cycle, hence for a given journey, a smaller battery should be used. The most overpriced component of an electric or hybrid vehicle is the propulsion battery. At low speeds, the engine-driven generator can be used to sustain the charge in the battery to provide extended electric driven miles. At highway speeds, the engine can be mechanically linked to the drive wheels, thereby improving the efficiency of the system.

A. Abbreviations

1) CVT-Continuous variable transmission.
2) e-CVT-Electronic continuous variable transmission.
3) BMS-Battery management system.
4) BEV-Battery electric vehicle.
5) EV-Electric vehicle.
6) HEV-Hybrid electric vehicle.
7) ICE-Internal combustion engine.
8) PHEV-Plug-in HEV.
9) MPG-Miles per gallon.

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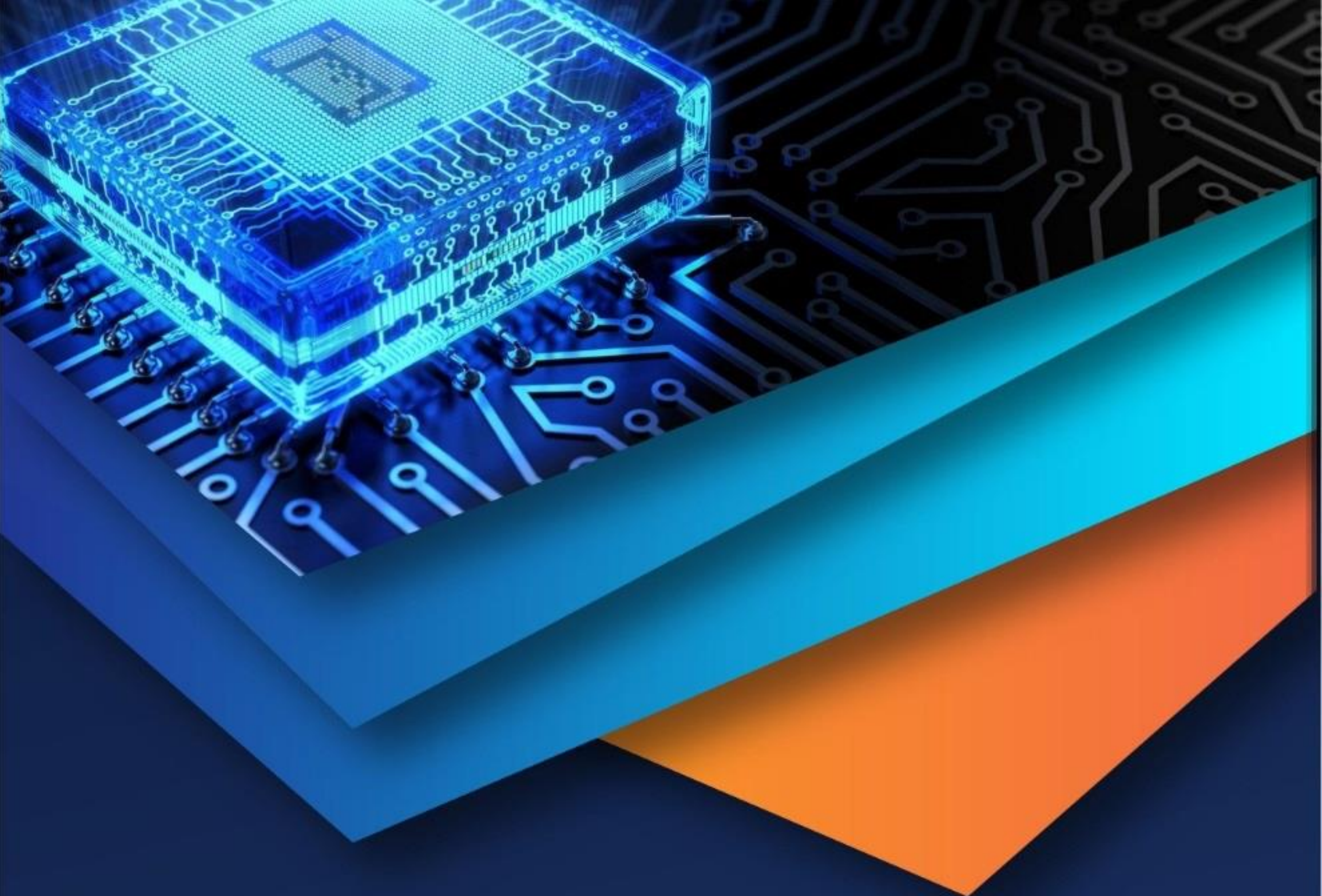

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