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RECENT DEVELOPMENTS AND A REVIEW: MULTI SPEED TRANSMISSION FOR ELECTRIC VEHICLE

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ABSTRACT
Due to high inflation, rising fuel prices and environment concern, there is an increase in demand for electric vehicle in the market. However, there are only two types of gearbox available for electric vehicles on the market: hub motor and single reduction. However, they are unable to provide the same amount of output as a vehicle powered by conventional fuels. Therefore, the goal of the analysis is to investigate how a gearbox used in conventionally powered automobiles may be applied to an electric vehicle. So, this paper covers the major details regarding the transmission systems used in the electric vehicle like, Continuous Variable Transmission (CVT), Dual Clutch Transmission (DCT) etc. Here the results of various research in regarding transmission in EV are compared for the required criteria. In this paper the comparisons are carried out from the dynamic point of view and the economic point of view. According to that, the CVT employed vehicle shows more promising result compare to other transmissions. But there are certain transmissions on which if the proper research is carried out then maybe they are going to give the better/satisfying results.

Keywords: *Electric Vehicle, Transmission System, Performance Criteria, multi speed transmission, etc.*

1. INTRODUCTION
Electric vehicle (EV) technological advances underwent slow growth between the 1830s and 1930s, with the primary emphasis being on traction motor, battery capacity, and charging infrastructure [1]. The need for EVs was once again identified during the oil crisis of the 1970s because to their significant benefits over traditional internal combustion engine (ICE) vehicles. While an ICE can convert only 12–20% of the total fuel into useful wheel torque [2] and have a maximum efficiency of 40% [3], an EV can generate wheel torque through an electric machine or motor that can deliver more than 85% efficiency [4]. Although a few of the main objectives of EV research is to improve motor technology for electric propulsion, the idea of using a multi-speed gearbox system to improve motor performance in EVs is still quite recent. Also drivetrain electrification has caused a lot of change in the automotive sector. Battery electric vehicle (EV) sales has gone up tremendously over the previous ten years and made up 2.5% of the global market in 2019 [5]. According to the International Energy Agency, EV sales will increase by 36% yearly to 245 million vehicles globally in 2030, a 300% increase from 2020 [6]. Light-duty electric drive vehicle sales in the United States increased by double in between 2017 and 2018, from 104,492 to 241,912 [7] (Fig. 1), according to the Transportation Research Centre at Argonne National Laboratory.

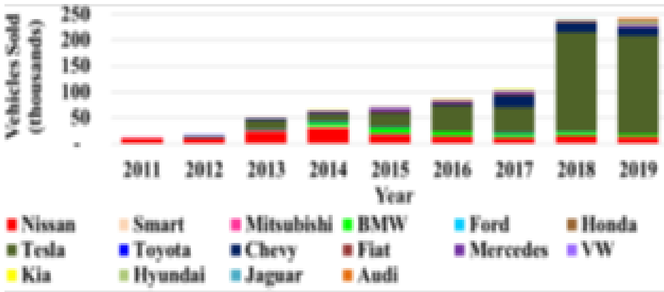


Fig. 1: Light-duty EVs sold in the United States from 2011 to 2019 per companies [7] [54].

Therefore, the electric drives market is also expected to grow and reach $17.6 billion by 2027, with a compound annual growth rate of 18.8% during the forecast period. [8]. Currently, single-speed gearbox-equipped EVs are the market leaders [9]. In order to achieve simplicity, cheap cost, efficiency, and acceptable acceleration and top speed, single-speed architecture is used in EVs like the Chevrolet Bolt and Chevrolet Spark [10], [11]. However, a single-ratio gearbox has certain limitations because it can't always guarantee that the electric traction machine (EM) and inverter will operate in the zone of greatest efficiency [12].Many different vehicle categories, including minivans, vans, and light to heavy-duty trucks, will become electrified as the EV industry develops [13, [14], [15]. For these vehicles, multi-speed gearboxes may be better suited to meet their weight, towing, off-road, and top speed requirements. The adoption of a gearbox control [16] and shift strategy [17], [18], as well as the usage of a multi-speed gearbox, may increase the cost of constructing an EV. Conventional multi-speed gearboxes typically have inferior efficiency than single-speed gearboxes [19]. Still, research indicate that multi-speed gearboxes have the potential to lower the overall energy consumption of the vehicle, which might translate to a longer driving range with a smaller battery pack, greater dynamic performance, and grade ability.

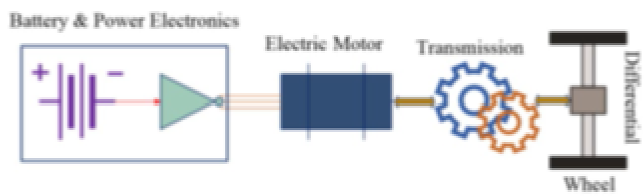


Fig. 2: Layout of the Electric Vehicle Transmission System.

Better drivetrain efficiency and vehicle performance may be attained by creating an efficient transmission system and integrating it with the current EV powertrain system (Fig. 2). To optimize the performance of the vehicle, an electric vehicle (EV) may be driven by have a gearbox system between the electric motor and wheel [20].Recent research has shown that multi-gear ratio systems can enhance drive wheel torque by 35% and decrease energy consumption by 2 to 20% for a range of driving cycles [17], [19], [21], and [22]. Three key quality metrics—dynamic performance, energy consumption, and driving comfort—are commonly used to assess a multi-speed gearbox's performance in electric vehicles (EVs) [23], [24], [25]. Driving comfort is the hardest of these to quantify, despite some attempts to model this feature [26]. The speed and torque of the electric motor must be properly tuned to avert jerk during gear changes in order for higher comfort and lower noise, vibration, and harshness (NVH) [12]. Furthermore, the shift schedule needs to be established to prevent shift hunting, which refers to frequent gear changes that compromise comfort and effectiveness [27].

This paper aims to provide a comprehensive review of academia and industry’s effort to improve EVs’ energy efficiency and dynamic performance via multi-speed gearboxes. This study will look at several types of multi-speed transmissions used in EVs and evaluate recent efforts to incorporate an AMT (automatic manual/mechanical gearbox) into an E-V. Regarding range, comfort, and driving circumstances, the multi-gear system and direct-drive system performances within the EV platform will be compared. Though adding more than one gear to an electric vehicle's engine has been shown to boost performance, it has also been discovered that, due to weight and space restrictions, selecting the right number of gears for a given application is crucial. To study the advances of EV transmission systems, gear ratio optimisation techniques, gear shifting tactics to minimise torque interruption during gear switching, and, lastly, additional transmission loss will be comprehensively explored and analysed.

2. DIFFERENT VARIANTS/TYPES OF MULTI-SPEED TRANSMISSIONS:

Many of the currently used transmission topologies are appropriate for EV applications. Small passenger cars to large commercial trucks are all covered by them. Manual transmissions (MT), automated manual transmissions (AMT), dual-clutch transmissions (DCT), automatic transmissions (AT), and continuously variable transmissions (CVT) are the five conventional categories for gearboxes. Infinitely variable transmissions (IVT) [28], magnetic gear transmissions (MGT) [29], and inverse-automated manual transmissions (I-AMT) have also been studied by researchers. With the exception of the AT, which is only appropriate for cars powered by internal combustion engines (ICE) due to its usage of a torque converter [30], all gearbox types are detailed in detail in this portion.

The MT, as seen in Fig. 3, is the traditional gearbox structure. The master clutch, which separates the engine from the gearbox, is engaged by the driver while manually shifting gears [31]. When the driver engages the shift lever to pick a gear, the synchronizer mechanically syncs the gears' speed with the rotating differential, driving the wheels. Some ICE-powered vehicles that have been converted to EVs utilize the common MT [32]. Although MTs are dependable, inexpensive, and low maintenance [33], they are rarely, if ever, utilized in production electric vehicles because the way the driver uses the gearbox has a significant impact on the ride, system efficiency, and clutch life.

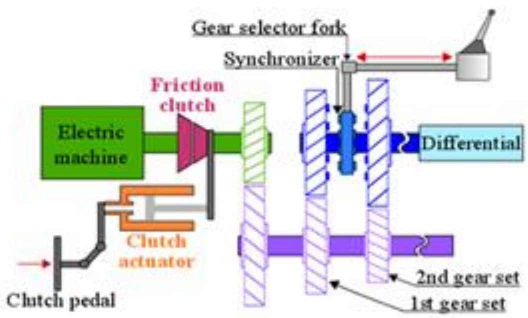


Fig. 3: n-Speed Manual Transmission (MT) [54]

An alternative to the MT is the AMT, which is shown in Fig. 4, in which actuators that are electromechanical or electrohydraulic engage the synchronizer(s) and change gears. [31]. For ICE cars, the AMT would have a clutch, but since motor speed and torque can be precisely regulated in EVs, this is not required. An automated gearbox control unit (TCU), as seen in Fig. 4, manages the gear shifting. The synchronizer is released, the motor torque is set to zero, the motor speed is changed to match the new gear, and then the synchronizer is re-engaged. This action disrupts the torque, which prevents a totally seamless gearshift. The AMT can accomplish smooth shifting by using an eddy current torque bypass clutch, as suggested in [34], which makes it better suited for electric traction systems. The AMT is a good option for EV applications owing to its low manufacture and maintenance cost, simplicity, ease of installation, and efficiency, even though it has never been widely used in ICE-powered cars [30].

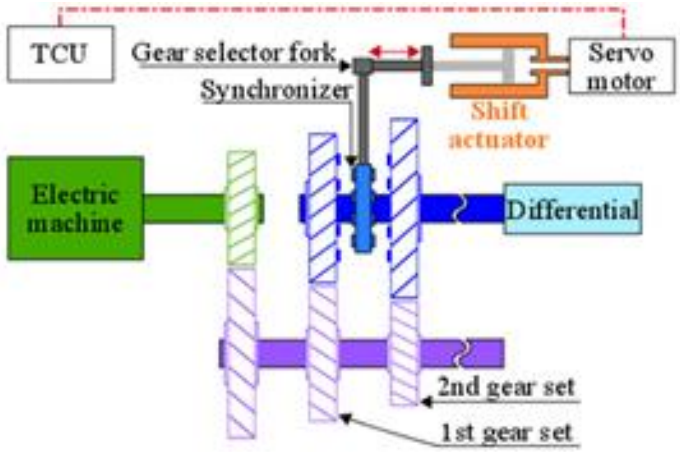


Fig. 4: n-Speed clutch less Automated Manual Transmission (AMT) [54]

I-AMT is essentially similar to an AMT, with the exception that it uses a clutch in place of a synchronizer to link the second gear, as seen in Fig. 5. The synchronizer engages or disengages the first gear, and the clutch blends in power. This innovative arrangement decreases torque interruption while shifting by around 50% compared to a conventional AMT, as suggested for EVs in [35].It could be able to fully compensate for torque and achieve smooth gear shifting with better controls [35].

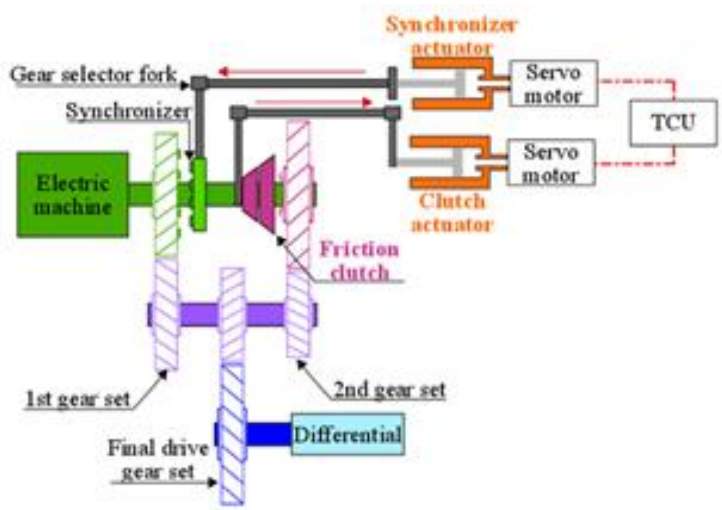


Fig. 5: Two-Speed Inverse Automated Manual Transmission (I-AMT) [54]

The DCT was launched in Porsche and Audi automobiles in 2003 with the goal of combining the benefits of MT and AT without the torque interruption inherent in AMTs [36]. The DCT, as seen in Fig. 6, comprises two shafts, one for odd gears and one for even gears, which are independently clutched to the motor. By disengaging one clutch while engaging the other and regulating the clutches concurrently, smooth shifting may be accomplished [31]. The design and effectiveness of the DCT can be significantly influenced by the clutch type, whether dry or wet [30]. A dry clutch has no oil on the clutch plates, which reduces loss but makes it challenging to dissipate heat [37]. A wet clutch contains oil on the clutch plates, which offers a nice medium for cooling but causes high drag and fluid churning loss.

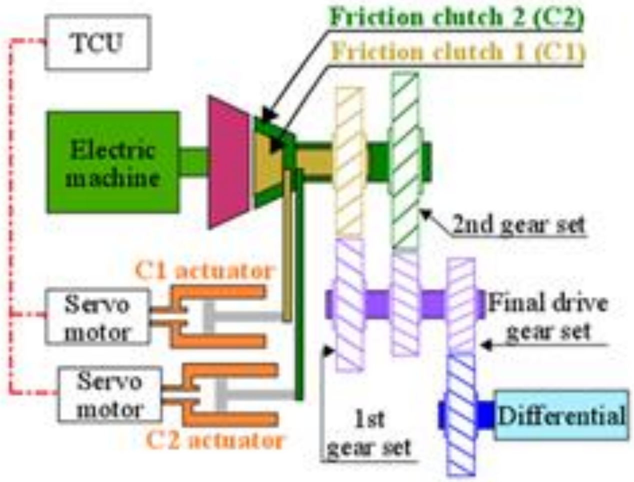


Fig. 6: Two Speed Dual Clutch Transmission (DCT) [54]

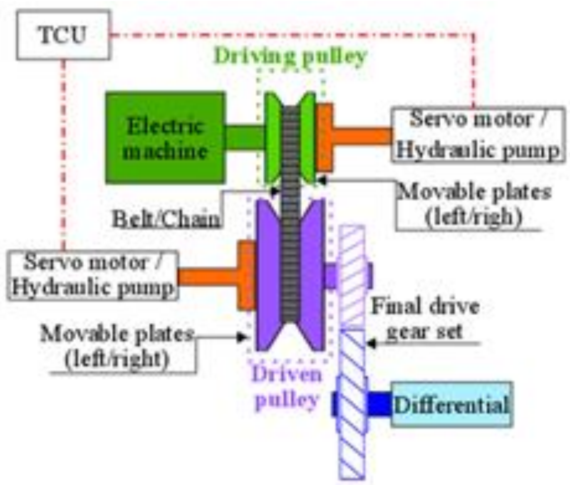


Figure 7: Continuously Variable Transmission [54]

As seen in Fig. 7 & Fig 8, a CVT employs use of tapered discs, a belt, or chain to enable the gear ratio to continuously vary from the minimum to the maximum ratio. A CVT may maintain the motor working at its highest efficiency points for a considerably higher amount of the time than a normal gearbox with set ratios. Due to friction between the belt or chain and the taper discs, which are pushed closer together or further apart to change the gear ratio, there is a substantial power loss in CVTs [31]. Also, force must be applied to the taper discs in order to hold them in place, and in some cases, such as when an ICE vehicle is starting from a stop, the chain or belt may slip, leading to additional loss. The CVT is the least effective gearbox type as a result of each of these loss-causing factors. Many studies have looked at CVTs for EV applications due to their smooth operation, lack of torque interruption, and capacity to run the traction machine at a variety of speeds

By combining a fixed ratio and a planetary gear set, a CVT's lowest gear ratio may be decreased to zero or even negative, leading to a transmission in which the ratio of input to output speeds is infinite [38]. In either the series arrangement (see Fig. 9)) or the parallel configuration (see Fig.10), the planetary gear set can be directly coupled to the motor shaft. According to the kinematic formulae for the gearbox, the range of gear ratios that may be used with the IVT depends on the CVT, fixed, and planetary gear ratios [38]. The primary benefit of the IVT is that the lower ratio may be zero, enabling an ICE to run at idle without a clutch, which is what the CVT would require

[39]. There is no discernible advantage of the IVT over the CVT for EV applications because electric machines may generate their entire torque at zero speed.

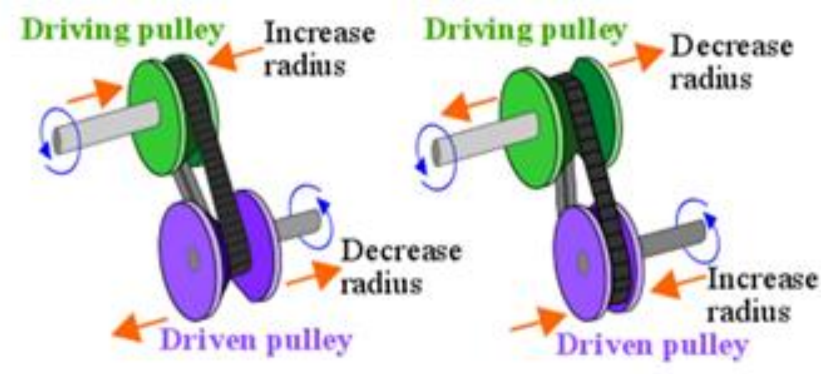


Figure 8: Working of CVT [54]

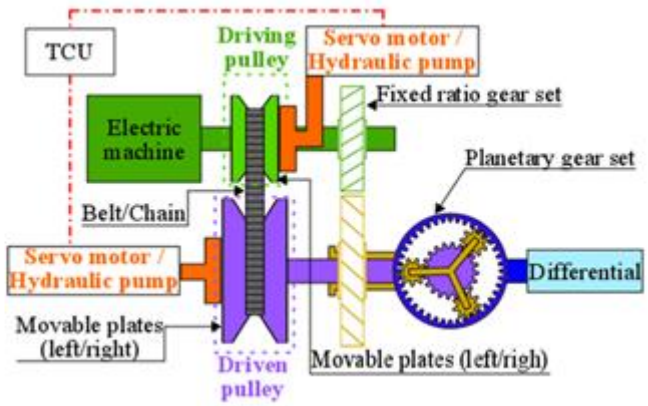


Figure 9: Parallel Infinitely Variable Transmission [54]

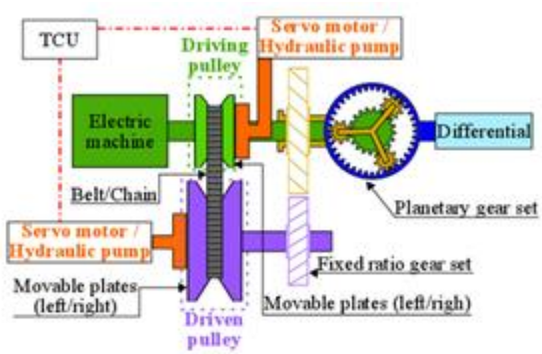


Figure 10: Series Infinitely Variable Transmission [54]

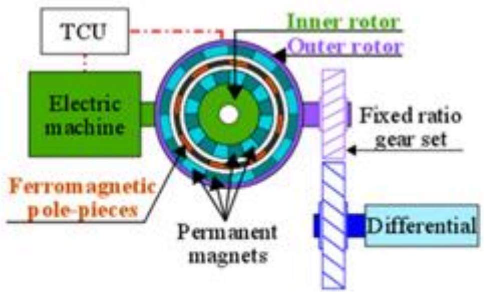


Figure 11: Co-axial Magnetic Gear [54]

A magnetic gear transmits force via a magnetic field as opposed to real gear teeth meshing. As shown in Fig. 11 and 12, permanent magnets are employed in place of teeth, and the ratio of magnetic pole pairs on the inner and outer rotors, or planetary type gears, sets the gear ratio. Because they are contactless, lubrication-free, and constructed with overload protection, magnetic gears are preferred. However, magnetic gears require a lot of magnets (14.7 kg per prototype EV wheel motor in [40]), which makes them uneconomical. The efficiency of magnetic gear motors is similarly poor, with each wheel motor losing roughly 2.5 kW of power at 100 km/h in [40], translating to an efficiency of only about 75% for highway driving. This makes magnetic gear motors unattractive for EVs.

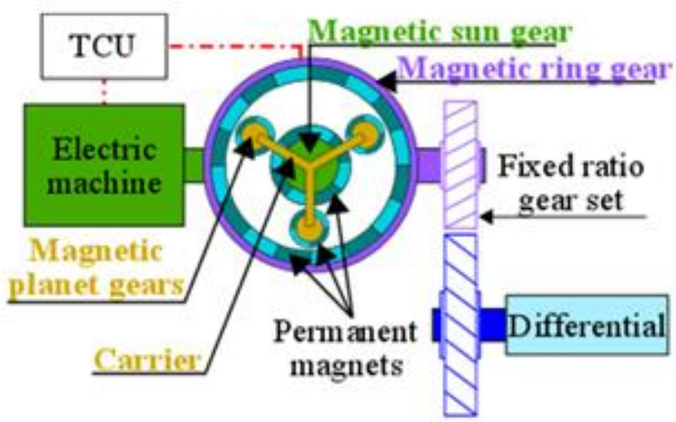


Figure 12: Planetary Magnetic Gears [54]

Here not much research is carried out in the Magnetic Gear Transmission. Still on it the research is ongoing so the data for it is insufficient to make any comparison & predict the proper performance.

Also in Electric Vehicle with Multi-Speed Transmission uses AMT (including DCT), IVT & CVT. Various elements of multi-speed gearbox in EV platforms, including performance, gear ratio, and shift scheduling approaches, are being investigated by researchers. Consequently, they provide a practical solution for the necessary dynamic and economic performance. Gearbox losses, cost penalties, etc. These characteristics of multispeed gearbox have been studied by researchers, thus this topic will be the focus of the next parts. So this article focuses on exploring the best possible transmission for the Electric Vehicle.

3. Performance/Efficiency with the Multi-Speed Transmission:

Similar to a conventional ICE vehicle, the addition of a multi-speed gearbox to an electric car serves two purposes: first, to increase operational economy by maintaining the motor working within its most efficient operating range; and second, to provide passenger comfort in a range of driving conditions. The addition of many gears to an electric vehicle's motor leads to the improvement of:

1. Dynamic ability

a) Acceleration Ability

b) Gradeability

c) Top Speed

2. Economic sustainability

a) Driving Range

b) Energy Consumption

3.1. Dynamic Performance:

The dynamic performances are related to top speed, acceleration ability, and gradeability. Additional explanations on how to measure or estimate the dynamic performances of EVs were provided by Ehsani et al. [41] (Table 1). The amount of time needed to accelerate from a stop position to 60 or 100 km/h is a measure of the initial acceleration capacity. In reality, passing acceleration is overtaking acceleration, and it is often determined by how long it takes to accelerate from 60 km/h to 80 km/h. While automobiles must travel on steep roads, gradeability refers to the capacity to ascend. The percentage of gradeability is determined by the gradient or slope of the road. For instance, a road with a 100% gradient has a 45° inclination angle between the horizontal and the road surface plane. Generally speaking, a vehicle is said to have sufficient gradeability if it can go at a certain speed (i.e., 30 km/h) on a road with an approximately 40% gradient or 22° inclination angle.

Table 1: Vehicle Dynamic Performance Criteria.

Dynamic Performance Criteria	Definition
Initial acceleration ability	Time needed for a vehicle to accelerate from a given speed to zero
Passing acceleration ability	Time to increase the speed of the vehicle from a low speed
Gradeability	Ability to travel at a set pace on an uphill evaluated by the road's grade and expressed in percentage
Top speed	Maximum possible speed for a vehicle

The data in Table 2 is compiled from several research and demonstrates that passenger E-cars with various multi-speed gearbox systems perform that is better economically and dynamically than those with single-speed gearbox systems. It should be noted that these studies are conducted, albeit they may not always take into account the exact same electric motor capacity or vehicle mass. Instead, the data in these tables aids in the creation of a basic knowledge of how much performance gain in EVs can be accomplished with multi-speed gearbox system compared to those with single speed system.

Table 2: Passenger electric car's dynamic performance at various traction motor capacity.

Authors	Motor Capacity kW (Nm)	Transmi-ssion type	Top Speed, Km/h	Acce. Time, Sec.	Grade ability
Zhou et al [42]	(250)	1-Speed	102	5.8	23.45
		2-DCT	198	4.9	43.75
Walker et al [43]	40/75 (135/250)	1-Speed	151	6.48	25
		2- DCT	222	5.22	45
J Ruan et al. [44]	95/125 (150/300)	1-Speed	112	7.3	48
		2- DCT	176	7.3	48
		CVT	181	6.3	60
Francis et al [45]	90 (250)	1-Speed	158	6.9	35
		2-AMT	>170	6.9	35

		2-DCT	>170	6.9	35
		CVT	>170	7.4	35

CVT- Continuously Variable Transmission

2-DCT- 2 Speed Dual Clutch Transmission

2-AMT- 2 Speed Automated Manual Transmission

The above mentioned data is a short explanation of dynamic performance various researches carried out regarding the transmission system for the Electric Vehicles. In the work by Zhou et al [42] & Walker et al [43] the states that the use of a multi-speed transmission system, significant improvements can be made in gradeability, which can increase by 80% to 86%, and maximum speed, which can increase by 47% to over 90%, as opposed to the modest improvements in initial acceleration ability, which can increase by 15.5% to 19.4% when compared to those who use a single speed system.

The author J Ruan et al [44] used three different types of the transmission that is one speed single reduction of gear ratio of 2.15, two speed DCT (Dual Clutch Transmission) with a first gear ratio of 2.15 & the second gear ratio of 1.49 & the CVT (Continuously Variable Transmission) with gear ratio varying from 0.5 to 2.5, shows that there is an improvement of 61% in top speed of CVT than SR & 57% in top speed of 2-DCT than SR. Additionally, the CVT accelerates more quickly from 0 to 60 km/h than the SR, increasing by 86%. The gradeability of the CVT is 25% higher than that of the SR & 2-DCT.

3.2. Driving Range :

Driving range in kilometers (km), energy consumption in megajoules (MJ), and changes in the battery pack's state of charge (SOC) are all examples of economic performance metrics. Battery SOC really refers to the battery's current capacity or the remaining charge that may be released from the battery pack [46]. A decrease in battery SOC indicates that a certain quantity of charge, which may be measured in MJ, has been released from the battery over a certain period of time. For instance, the amount of energy used to discharge 10 coulombs (C) of charge from a 12 volt battery in an hour, or 3600 seconds, is equal to 12V*(10C)*(3600s) Joules, or 0.432 MJ. SOC in the battery pack may therefore be used to represent the energy usage in EVs. Standard driving cycles, such as the New European driving Cycle (NEDC), Urban Dynamometer Driving Schedule (UDDS), Highway Fuel Economy Test (HWFET), Chinese City Style (CCS), etc. are typically used to evaluate the economic performances of vehicles. Most of this drive cycle data are easily obtainable through the Matlab/Simulink environment's drive cycle toolbox.

As mentioned above there are various parameters that the researchers use for the analysis of the economic performance of a vehicle. Some use the average power consumption, while some uses the drive range to a vehicle for the cycle while some uses the energy consumed for the certain distance, whereas some uses the SOC of Battery, and some uses the motor efficiency for the vehicle etc.

Table 3 shows the economic performance regarding the drive range in kilometer for the different research. Walker et al. [43] discovered that a two-speed system had a reduced driving range than a single-speed system for UDDS drive cycle. Whereas the Zhou et al. [42] shows that the drive range of 2 speed DCT by 4.17% than single reduction for the NEDC drive cycle. In another study by the Ruan et al. [45] shows that the CVT shows the increment of 8% in the driving range then SR for the HWFET drive cycle and for the 2 speed DCT the drive range is almost 8% more than SR for the same cycle.

Table 3: Performance in terms of drive range for passenger electric cars with various traction motor capacity.

Author	Motor Capacity kW (Nm)	Transmission Type	Drive Cycle	Drive Range, km
Zhou et al [42]	(250)	1-Speed	NEDC	126.55
		2-DCT		131.83

Walker et al [43]	40/75 (135/250)	1-Speed	HWFET	157.6
		2- DCT		141.8
J Ruan et al. [44]	95/125 (150/300)	1-Speed	HWFET	158
		2- DCT		173
		CVT		174

3.3. Consumption of Energy

Energy consumption is the total amount of energy required for a given process and is measured in kilowatt hours (kWh). All of the energy needed to carry out an action, create something, or just occupy a structure is referred to as energy consumption. Here are a few illustrations, Total energy consumption at a factory may be calculated by looking at how much energy is used during a manufacturing process, such as when making vehicle parts. This will cover any energy source required to convert the raw material into the finished product, such as water, electricity, gas, etc. Energy use in a home comprises the use of electricity, gas, water, and any other fuel required to maintain a comfortable standard of living. The amount of energy used by transportation includes what it takes for diesel or petrol cars to operate.

As per Miri et al. [47] the term "EV energy consumption" often refers to the total of the following:

- The energy needed to move the vehicle forward at the wheels,
- The energy lost along the powertrain,
- The energy needed to run auxiliary devices.

Applications for energy consumption estimation is helpful for:

- Making an estimate before to a journey to arrange a route as part of an eco-routing system. The algorithm chooses the most energy-efficient route for a given destination depending on the traffic and environmental factors at the time.
- Second-by-second estimation to offer real-time data on the energy use of the vehicle.
- Eco Approach and Departure, which offers suggestions on how to use less energy while approaching signalized junctions. Examples include figuring out the fastest method to stop on a green light or the best speed to get to the next traffic light, then displaying that information to the driver.

Table 4 shows the energy consumption data for various kinds of the transmission on different kinds of drive cycle. It's a collection of various researches in a single table so that a simple comparison can be made.

In Francesco et al [48] taking each drivetrain system in assessment, the energy consumption has been estimated. The IVT gearbox with Type I power flow has the optimum performance. The estimated energy consumption for the UDC and J10-15 is 186.6 Wh and 330.2 Wh, respectively. Although the power losses in the planetary gear and the fixed ratio drive of the IVT have been ignored in these calculations, as well as the IVT-I's higher cost, larger size, and heavier weight compared to HT drive, the simulated energy consumption of the HT drive is only 0.2% and 3.5% larger, respectively, in the UDC and J10-15. As a result, the HT gearbox is the most practical option. The ability to alter the operating point of the EM enables the HT to achieve energy consumption reductions of around 13% and 20% in the two driving schedules, relative to the 1G transmission, as compared to the 1G and 2G transmissions. This is accomplished despite the fact that the HT transmission's efficiency is, on average, on level with that of constant ratio drives.

In the research by Hoffman et al [49] uses the CVT with transmission ratio varying from 0.4 to 2.40 while gear box with the five speed ratios of 0.14, 0.26, 0.40, 0.54, 0.67 & also the Clutch model is used for the Manual Transmission. Here, the author find out that depending on the drive cycle (FTP75-NEDC) and optimizing the shifting strategy, the energy consumption can be reduced by relative values between 1%-4% and 5%-6% (compared to an optimized single gear) due to shifting (both standard and optimal approach). The consumption of energy varies significantly amongst the various gearbox types. Due to the fact that an optimized single gear still uses between 8% and 10% more energy than a CVT with an optimized shift strategy. As per the research CVT is generally the most energy-efficient transmission type if the transmission efficiency of all the transmission types is considered to be equal. As an illustration, a 7% energy savings is determined as compared to a well-chosen fixed-gear ratio gearbox type. In the high efficiency areas, the EM is used by the CVT much more frequently.

The only research of Alfonso et al. [50] obtained the higher energy consumption for the CVT when compared with other transmission system, this is because the researchers have developed their own transmission system for the electric vehicle that is the combination of the various gear ratio manual transmission, and the CVT which they used is of higher configuration. Due to this reason the energy consumption of the CVT is higher than the other transmission system. The outcome states that the energy consumption of CVT is about 8% more than the Single reduction whereas the energy consumption of manual transmission is 3% less than the consumption of the single reduction. Also the energy consumption of CVT is about 11% higher than that of the energy consumption of the manual transmission.

Table 4: Performance in terms of energy consumed for passenger electric cars with various traction motor capacity.

Author	**Motor Capacity kW (Nm)**	**Transmission Type**	**Drive Cycle**	**Energy Consumed**
Francesco et al. [48]	28 (108) Max.	CVT (FT)	UDC	206Wh
		CVT (HT)		187Wh
		1-Speed		209.9 Wh
		2-Speed		205 Wh
		IVT- I		186.6 Wh
		IVT- II		193.6 Wh
		CVT (FT)	J10-15	372.75 Wh
		CVT (HT)		341.65 Wh
		1-Speed		395.92 Wh
		2-Speed		368.26 Wh
		IVT- I		330.5 Wh
		IVT- II		346.62 Wh
Hoffman et al. [49]	36 (115) Max.	1-Speed	NEDC	1.55 kWh
		DC Manual		1.61 kWh
		Manual		1.62 kWh
		CVT		1.59 kWh
		1-Speed	FTP-75	2.81 kWh
		DC Manual		3.23 kWh
		Manual		3.31 kWh
		CVT		3.14 kWh
Alfonso et al. [50]	40.3	1-Speed	NEDC	260 Wh
		4-Manual		252 Wh
		CVT		281 Wh

4-Manual: 4 Speed Manual Transmission

In the research of J Ruan et al. [51] used the model of B-class and E-class as there is two section of the it in the Table 5 of it. For the transmission in the B-Class, the gear ratios for the 1-speed single reduction is the 2, for the 2-speed DCT are 2.7, 0.9, for the 3 speed DCT are 2.7, 1.6, and 0.9 & for 4-speed DCT are 2.7, 1.9, 1.3, 0.9 while transmission ratio for the CVT ranges from 0.72 to 2.16. For the E-Class the gear ratios for the 1-speed single reduction is the 2.5, for the 2-speed DCT are 3.6, 1.3, for the 3 speed DCT are 3.6, 2.2, and 1.3 & for 4-speed DCT are 3.6, 2.6, 1.8, 1.3 while transmission ratio for the CVT ranges from 1 to 2.88. For the B-Class, the energy consumption of the CVT is less than all the other type of the transmission. The energy consumption of CVT is 31% than that of the 1 Speed gear transmission while energy consumption of other transmission systems are 12.6%, 15.1% & 11.6% less than single speed transmission. For the E-Class, the energy consumption of the CVT is also less than all the other type of the transmission. The energy consumption of CVT is 30 % than that of the 1 Speed gear transmission while energy consumption of other transmission systems are 9.5%, 9% & 14.9% less than single speed transmission. By the comparison of all the above data it can be estimated that the use of the electric vehicle propelled with the CVT is more efficient than the other transmission used in the EV. Even the 4 Speed DCT is also somewhat effective for the use.

Table 5: Performance in terms of energy consumed per 100km for Electric Vehicles with various traction motor capacity.

Author	Motor Capacity kW (Nm)	Transmission Type	Drive Cycle	Energy Consumed per 100 km (kWh/100km)
J Ruan et al [51]	65 (250)	1-Speed	FTP-75	10.3
		2-DCT		9.04
		3-DCT		8.74
		4-DCT		9.10
		CVT		7.02
		1-Speed	HWFET	11.6
		2-DCT		9.4
		3-DCT		9.1
		4-DCT		8.9
		CVT		8.07
		1-Speed	Combine	11
		2-DCT		9.2
		3-DCT		8.9
		4-DCT		9.0
		CVT		7.6
J Ruan et al [51]	110 (350)	1-Speed	FTP-75	18.8
		2-DCT		17.0
		3-DCT		17.1
		4-DCT		16.0
		CVT		13.2
		1-Speed	HWFET	17.1
		2-DCT		15.5
		3-DCT		15.6
		4-DCT		14.5
		CVT		14.1
		1-Speed	Combine	17.8
		2-DCT		16.1
		3-DCT		15.6
		4-DCT		14.5
		CVT		14.1

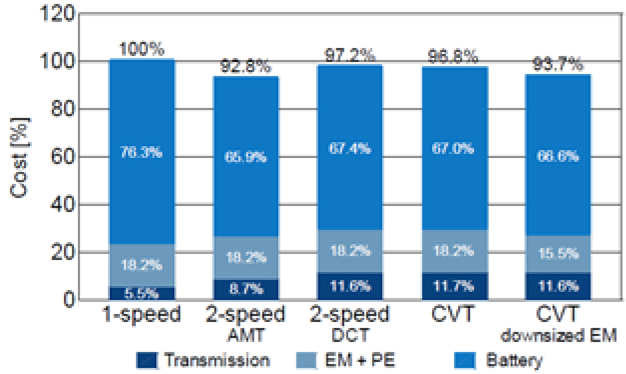
Francis et al [45]	90 (250)	1-Speed	WLTC	11.34
		2-AMT		9.81
		2-DCT		10.02
		CVT		9.96
		Opt. CVT		9.90
Ren et al. [52]	40 (240)	No gear	NEDC	8.33
		2-Speed		8.10
		3-Speed		8.01
		4-Speed		7.96
		CVT		7.89
		No gear	FTP-75	8.45
		4-Speed		7.77
		CVT		7.53

In the research of Francis et al. [45] vehicle simulations utilizing a backward model were used to assess the energy consumption of the various topologies. Software called Matlab was used to programme the simulation tool. Table 5 lists the simulation outcomes for the WLTC cycle. If transmission variability is incorporated, the amount of energy usage falls by 11.6 to 13.5%. A notable decrease of 40 to 50% is especially evident in the losses in the electric machine, power electronics, and battery. Additional gearbox losses caused by idle gears, synchronizers, inactive clutches or the variator reduce this gain. However, the slower input speeds also result in lower gearbox drag losses. Here the energy consumption is reduced by about 13% by using the CVT which is the lowest among the all of them. So, a CVT and a smaller electric motor combined with an integrated system approach result in competitive energy usage.

In Ren et al. [52] shows the use of different transmission for the electric vehicle. Here also it states that the use of CVT is the most effective on comparing to another transmission. The use of CVT will reduce the energy consumption by 5% which is highest for the all transmission.

4. Cost Factor:

As per the Francis et al [45] the use of a CVT provides two options to reduce driveline cost. First, the lower energy consumption makes it possible to reduce the battery size while maintaining the same range. Second, the lower driveline loads and speeds present a chance for component downsizing. The electric machine's reduction in size was previously discussed. The primary forces behind cost reduction are: Reduced centrifugal stresses in the motor due to the reduced maximum speed make more affordable design options possible. A lower maximum torque allows for fewer windings and less copper, which leads to smaller dimensions. A decrease in maximum torque also makes it possible to use less expensive magnet materials in place of rare earth elements like cobalt. The projected effect on system cost is depicted in Figure 13. The entire system can yield a cost benefit of 3–7%. The advantage for the reference electric vehicle when the CVT is included results from the battery's smaller size, which outweighs the CVT's additional cost. When compared to single-speed and two-speed gearboxes, the CVT with a scaled-back electric motor performs competitively. The added comfort provided by power shift technology for two-speed transmissions results in higher transmission and battery costs. The greater energy consumption brought on by the additional gearbox losses results in a higher battery cost.



The maximum ratio i_{Gmax}, the number of gears z, and the input torque T_1 may all be connected to the gearbox relative selling price (RSP) using the approach of design utilising characteristic values[53], as stated in Eq. (1)

$$RSP = 0.0183 \times (i_{Gmax} \times T_1)^{0.512} z^{0.256}$$

On the basis of the above formula the RSP of two types of vehicles with DCT & CVT transmission in J Ruan et al [51] is been calculated and the data is mentioned in table 6,

This shows that the selling price of the CVT is 34.61% higher than that of the single speed reduction. Where the RSP for 4-DCT is also suitable.

Table 6: Relative Selling Price for the transmission

Model	Transmission	RSP Value
B-Class	1-Speed	0.52
	2-DCT	0.62
	3-DCT	0.69
	4-DCT	0.74
	CVT	0.86
E-Class	1-Speed	0.64
	2-DCT	0.77
	3-DCT	0.85
	4-DCT	0.92
	CVT	1.08

Also the cost saving in the electricity that is consumed & battery preparation/manufacturing cost is shown in the table 7 & table 8. All the cost values are in US Dollars.

Table 7: Electricity and battery component production costs are reduced for the B-Class PEV.

Cost Charge	1-Speed	2-DCT	3-DCT	4-DCT	CVT
Battery	0	-4000	-4000	-4000	-8000
Electricity for 250000 km	0	-1666	-1944	-1852	-2550
Transmission	0	+595	+660	+707	+822
Total cost saved by add. Gear	0	-5099	-5284	-5145	-9728

Table 8: Electricity and battery component production costs are reduced for the B-Class PEV.

Cost Charge	1-Speed	2-DCT	3-DCT	4-DCT	CVT
Battery	0	-3200	-3200	-5600	-11000

Electricity for 250000 km	0	-1574	-1481	-2500	-3150
Transmission	0	+959	+1055	+1139	+1333
Total cost saved by add. Gear	0	-3815	-3626	-6961	-12817

As per the research shown above, the manufacturing cost of the CVT is less than all other as the comparison is taken with the reference of the 1-speed transmission. The comparison the shows that the components cost of manufacturing for the CVT is less also the cost reduction for the 4-Speed is also suitable. From the viewpoint of the consumer, the CVT's accomplishment in the B-Class PEV is excellent compared to the two-, three-, and four-speed vehicles' differences as nearly twice as many other candidates. From the Original Equipment Manufacturer's viewpoint (OEM), who is more concerned with the cost of production, in this investigation, the battery and CVT gearbox is also the winner, and the gearbox has two speeds stepped is a preferable option compared to three- and four-speeds. The best option for the E-class PEV is still a CVT as well as customers, even if four-speed performance in this area surpasses two-speed.

5. CONCLUSION

As the results of various research shows that the EV is the best replacement of the conventional vehicles propelled by fuels like Petrol, diesel, etc. A feasibility study for the various transmission in an electric vehicle was performed. This system was compared with a single speed transmission, a two-speed AMT and a various-speed DCT options etc.

On the basis of the dynamic analysis carried out for the various transmissions in electric vehicle, CVT shows the better performance compare to any other transmission systems, whereas the range in DCT is also nice but when it is compared with the CVT it little bit shorter then CVT which shows that both have the equal dynamic performance potential if the research is carried out in the proper way in this transmission.

The drive range of the vehicle employed with the transmission is quite higher than the single speed transmission. There is an improvement in the range of the vehicle when there is transmission in that vehicle. Amongst the different transmission used in EV, as per the obtained data CVT & DCT car the good options for transmission in the Electric Vehicle.

All the kinds of the transmission systems on which the research has been carried for its used in the Electric Vehicle shows the good level of diminution in the rate of energy consumption. But as they are compared with each other the one with the highest diminution in energy consumption is the continuous variable transmission (CVT).

In the cost analysis the factors that arrives are the selling price, the manufacturing cost & the electricity costing for an Electric vehicle. The EV with the CVT has the higher RSP i.e. the relative selling price, whereas the cost of production of various components is less because the components with lesser values are also efficient with the transmission system applied in the CVT. Apart from CVT, 4-Speed DCT & 2-Speed AMT has the lesser cost of production and the lesser value of electricity consumed for the certain kilometer ride.

After the overall analysis of the situation, it is observed that ever kind of transmission has their own benefits, but after the comparison of all the aspects for the performance of EV, it is found that the CVT is the best option as a transmission for the Electric vehicles.

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