The 14th IFToMM World Congress, Taipei, Taiwan, October 25-30, 2015
DOI Number: 10.6567/IFToMM.14TH.WC.OS17.010

Comparing of single reduction and CVT based transmissions on battery electric vehicle

Jiageng Ruan[1], Nong Zhang[1], Paul Walker[1]

[1] University of Technology, Sydney

Abstract

With the deterioration of the air pollution, growing public concerns over the exhaustion of global fossil energy and the explosive growth of passenger vehicles, the improvement and popularity of electric vehicles (EVs) have increased in market share. The primary goal of EV powertrain design is achieving the same performance, e.g. launching and driving range, as that of Internal Combustion Engine vehicles. To realize this target, a novel propulsion system is proposed in this paper. A comparison of driving performance and energy saving are completed among single reduction, continuously variable transmission (CVT) and proposed system on EVs. The simulation results show that the optimized motor propulsion system has a significant improvement on battery energy saving, range extension and vehicle cost.

Introduction

Despite the long-term benefit of battery electric vehicles (EVs) to customers and environment, the initial cost and limited one-charge driving range present the major barrier for its wide spread commercialization. Therefore, it is necessary to pursue every possible avenue for minor efficiency gains. One of the possible methods is adding a multi-speed transmission system to EVs. A lot of researchers, e.g. Ren Q, Crolla D.A, et ac. have demonstrated that multi-speed gearbox can not only improve the overall drivability and motor efficiency, but also downsize the battery and motor. [1] Although, considering the cost and outstanding dynamic performance of electric motors, fixed ratio single reduction is widely adopted by most OEMs as a transmission system on EVs rather than multi-gear equipment. To achieve a better balance between dynamic and economic performance, an efficient, smooth-shifting and affordable multi-speed transmission is necessary for EVs.

Not all transmission systems used in Internal Combustion Engine (ICE) vehicles are suitable for EVs. Manual transmission and automated manual transmission have inevitable torque interruption, which will offset the EVs innate advantage-smooth driving. [10] And the priority purpose of adding a multi-speed transmission system to EVs is extending the one-charge driving range. Thus, the lower efficiency of automatic transmission itself excludes itself based on these requirements. [11]

CVT is possible to vary the transmission gear ratio without interruption of the torque flow. Therefore, an infinite number of ratios (between a minimum and maximum value) are possible. The key lies in its simple yet effective belt-and-pulley design. The CVT works with an all-metal chain that runs between cone-shaped curved pulleys. The transmission ratio between the engine and drive wheels changes in a smooth manner in relation to the variable axial gap between the pulleys. The gap defines the possible chain radii on the pulleys. Due to their mechanical layout and the need of torque converter to work with ICE vehicles, the efficiency of CVT is typically lower than that of single-speed ones and they can suffer from poor speed of response [3,4,5], particularly at launch [6]. As the gear ratio varying range in CVT is wide and continuous, the ratios control strategy needs to be compromised between fuel economy and drivability, which contributes to a poor speed response and dissatisfactory launching performance. [7, 8]

However, with the ability of 100% torque delivery from standstill, wide speed range and excellent dynamic control ability of motor, the requirements for transmission system design for EVs are much simpler than that for ICE vehicles. Specific to continuously variable transmissions (CVT), the torque converter and hydraulic system can be removed, which is the most inefficient and complicated component. Furthermore, the infinite number of transmission ratios allows motor to always run at its optimum speed. It will be different in comparison of potential benefits from the viewpoint of overall powertrain efficiency. The variable ratios range will be narrower, which means a lighter and more compact CVT. In addition, the new generation push-belt CVT has the ability to transfer more than 400 Nm torque, which the insufficient transmission torque capacity was usually regarded as the main drawback of CVT, covering full range of most daily-used engines and motors. [9].

In this paper, a structure simplified and gear ratio rearranged CVT based EV model is proposed and demonstrated. A smaller motor and battery pack are selected in model, thanks to the contribution of CVT, whilst same vehicle performance is preserved. Then, ratios varying range and shifting schedule, aiming to achieve better fuel economic performance, are designed. The energy saving of whole integrated powertrain is analysed, considering the efficiency improvement of motor and energy loss in CVT. A comparing of increased manufacturing cost and daily-use cost saving between single reduction and CVT based EVs are presented in final conclusion.

Powertrain Design Study

Simulation requirements and targets are listed in Table 1, vehicle specifications are provided in Table 2.

TABLE 1: Performance Requirements

Performance specification	Target performance
Acceleration 0-100km/h	12s
Top speed	120 km/h
Range @ 60kph	150 km
Range NEDC	100 km
Maximum Grade	30%

TABLE 2: Vehicle Specifications

Parameter	Description	Value	Units
m	Vehicle mass	1760	kg
r	Wheel radius	0.3125	m
	Gear ratio		-
C_R	Coefficient of rolling resistance	0.016	-
g	Gravity	9.81	ms^2
φ	Road incline	-	°
C_D	Drag coefficient	0.28	-
A	Vehicle frontal area	2.2	m^2
	Vehicle speed	-	m/s^2
Bat_v	Battery Voltage	380	v
Bat_c	Battery Capacity	72	Ah

TABLE 3: Assumed Vehicle Specifications

Parameter	Description	Value	Unit
	Assumed Motor Peak/ Rated Torque	300/150	Nm
	Assumed Motor Peak/ Rated Power	125/45	Kw
	Assumed Motor Max Speed	8000	rpm
	Single Reduction efficiency	0.95	
	CVT efficiency (Depend on gear ratio)	0.9-0.95	
	Torque converter efficiency	0-1	

Gear Ratio design for single reduction

The maximum speed achieved in the vehicle can be used to determine the upper limit of gear ratio of single reduction:

, thus:

7.9

The lower gear ratio limit is set based on the rolling resistance for a specified grade (Table 1) over the maximum motor torque multiplied by the overall powertrain efficiency. This is given in equation (2). For low vehicle speeds, the aerodynamic drag is assumed to be zero and φ=30%, T_{max_assume}=300Nm:

Using the data provided in Tables 2 and 3 the minimum usable gear ratio for different grades are presented below.

TABLE 4: Road grade design ratios

Grade	Design ratio
30%	6.0
40%	7.7

Based on the above results, the single reduction gear ratio is set to be:

Motor capacity design for battery electric vehicle

As we can see from figure 1, which is a typical permanent magnetic motor characteristics map, output torque varies with speed. From standstill to rated rotation speed, motor can provide constant maximum torque. Then, the available torque decreases with motor speed rising.

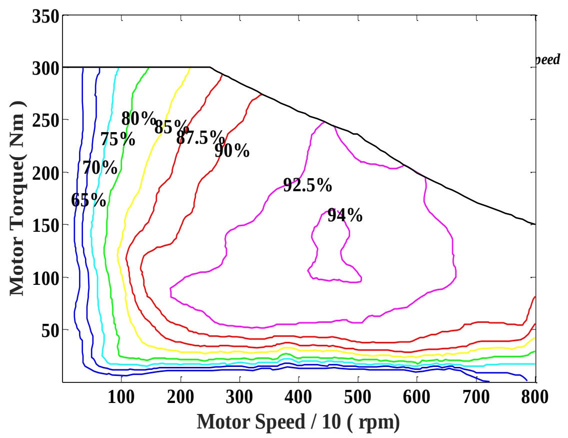


FIGURE 1: PM Brushless Motor Properties

The motor should have the ability to propel vehicle driving on designed maximum grade road a particular speed, which is usually used to determine the maximum available motor torque.

$$\frac{T_{motor}\eta i_g}{r} = \left(\mathrm{mg}C_R\cos\varphi + \mathrm{mg}\sin\varphi + \frac{\mathrm{C_D A}}{21.15}\mathrm{u}^2 + \delta\mathrm{m}\frac{\mathrm{d_u}}{\mathrm{d_t}}\right) \quad (3)$$

$$T_{motor\_max} \geq \frac{\left(\mathrm{mg}C_R\cos\varphi_{max} + \mathrm{mg}\sin\varphi_{max} + \frac{\mathrm{C_D A}}{21.15}\mathrm{u}^2\right) r}{\eta i_g} \quad (4)$$

The motor torque required for maximum road grade (30%) is related to the transmission efficiency and max gear ratio, which is shown in the figure 2:

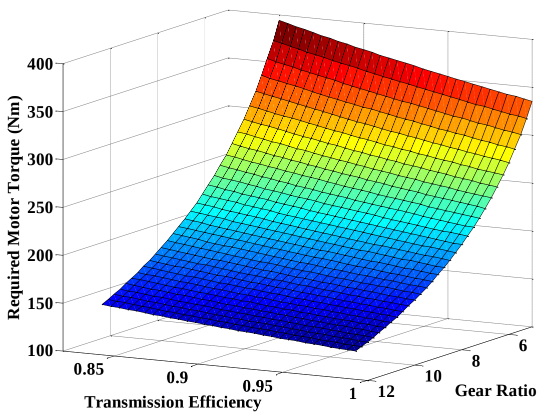


FIGURE 2: Motor torque design based on road grade

If, $\mathrm{u} = 15$ km/h , $i_g = 7.5$, $\eta = 0.9$, then,

$$n = \frac{u*1000}{3600} * \frac{60*i_g}{2*pi*r} = 955 \quad (rpm) \quad (5)$$

As shown in equation (3), the climbing speed is usually lower than the rated speed. Therefore, equation (4) can be used to determine the maximum motor output torque:

$$T_{motor\_max} \geq 242 \quad Nm \quad (6)$$

Except the torque, the power also needs to meet the requirement of vehicle driving on particular grades (30%) at certain speed (u=15 km/h):

$$P_{motor\_max\_grade} \gg \frac{\left(\mathrm{mg}C_R\cos\varphi + \mathrm{mg}\sin\varphi + \frac{\mathrm{C_D A}}{21.15}\mathrm{u}^2\right) u}{3600\eta} = 24.2\ (Kw) \quad (7)$$

The highest cruising speed is usually achieved from the motor maximum power on horizontal road. The required power for highway cruising can be calculated by vehicle dynamic motion equation via multiplying vehicle speed (m/s) on both sides of equation (1):

$$P_{motor\_max\_v} \gg \frac{\left(\mathrm{mg}C_R\cos\varphi + \mathrm{mg}\sin\varphi + \frac{\mathrm{C_D A}}{21.15}{u_{max}}^2\right) u_{max}}{3600\eta} \quad (8)$$

$$= 25.8\ (kw)$$

Figure 3 clearly demonstrates that the demanded power rises rapidly with design top speed increasing on graded road (φ =6%).

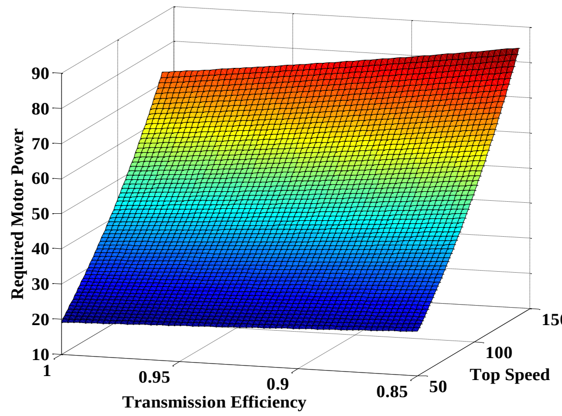


FIGURE 3: Motor power design based on top speed

In general, vehicle acceleration time can be calculated via formula (9) and (10)

$$\alpha = \frac{F}{m} = \frac{du}{dt} = \frac{\frac{T_{max}i}{r} - \left(\mathrm{mg}C_R\cos\varphi + \mathrm{mg}\sin\varphi + \frac{\mathrm{C_D A}}{21.15}\mathrm{u}^2 + \delta\mathrm{m}\frac{\mathrm{d_u}}{\mathrm{d_t}}\right)}{m} \quad (9)$$

$$t_{0-100} = \int_0^{100} \frac{21.15mr(1+\delta)}{21.15T_{max}i_g\eta - 21.15mrgC_R - C_DAru^2} du \quad (10)$$

Nevertheless, according to figure 1, T_{max} is not constant during its speed range and related to rotation speed. Thus, it is difficult to using above equations to achieve acceleration time. In this paper, a Matlab/Simulink model is used to obtain the accurate vehicle acceleration time, shown in figure 4&5. The gear ratio is fixed in single reduction scenario and varies in CVT scenario.

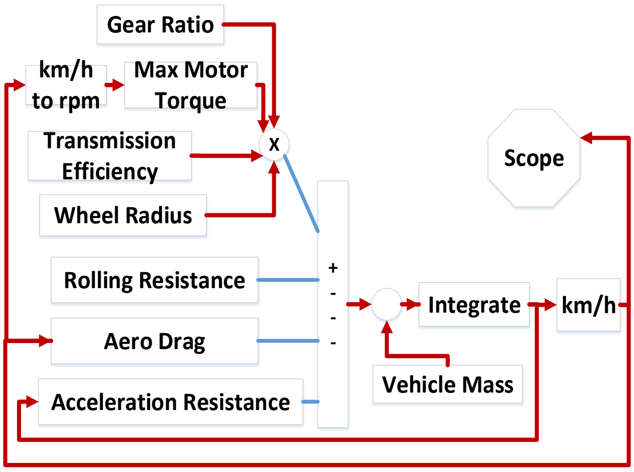


FIGURE 4: Acceleration time calculation

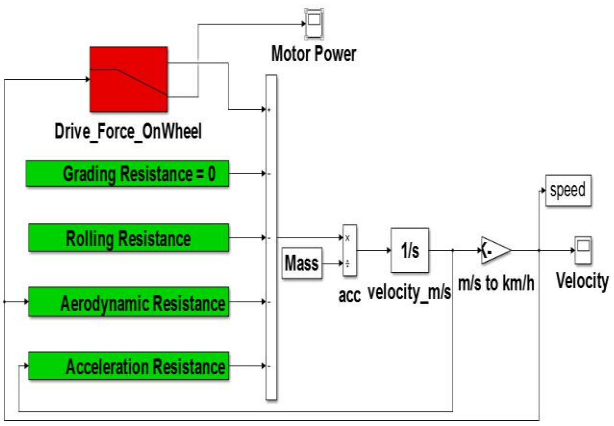


FIGURE 5: Acceleration time calculation Simulink® model

According to the simulation results, 0-100 km/h acceleration time of single reduction based EV is:

$$t_{0-100} = 15.5\ (s)$$

The output power curve during acceleration is shown in figure 6, based on torque and rotation speed:

$$P = Fv = \frac{Tn}{9550}(Kw) \qquad (11)$$

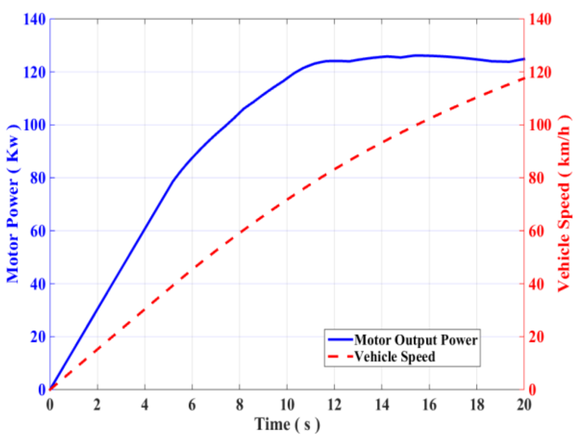


FIGURE 6: Output torque and acceleration time curves based on assumed motor size

This result is not qualified and 3.5s longer than expected. Increasing gear ratio do shorter the acceleration time, however, the top speed drops as well. Therefore, the top speed and acceleration time cannot reach the target value simultaneously in single reduction based EV.

Another approach to improve acceleration time is upgrading the assumed motor characteristics, including power and torque. The acceleration time is shorten to 11.7s, as shown in figure 6, after iterative motor size testing in figure 5 model. The maximum torque of new selected motor is:

$$T_{motor\_max} = 390\ (Nm) \qquad (12)$$

The required power to accelerate vehicle from standstill to 100 km/h in 12s is shown in figure 7:

$$P_{peak} = 165\ (Kw) \qquad (13)$$

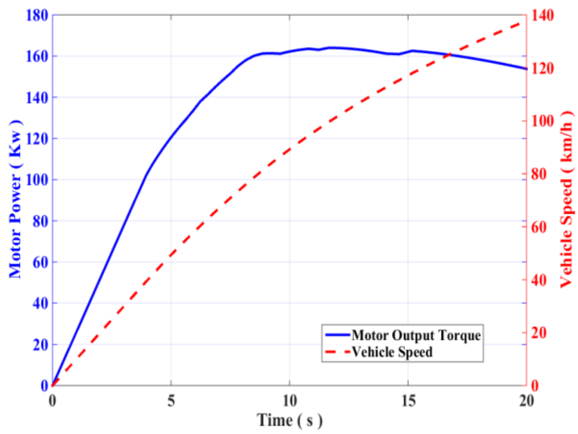


FIGURE 7: Output torque and acceleration time curves based on re-designed motor size

Motor specification design based on single reduction

Required specifications of motor for single reduction based BEVs are presented in table 5, based on equations (6), (7), (8), (11), (12), (13):

TABLE 5: Motor and vehicle specifications based on single reduction

Specification	Value	Unit
Grade based Maximum Motor Torque	242	Nm
Acc-time Based Maximum Motor Torque	390	Nm
Grade Based Maximum Motor Power	24.2	Kw
Top Speed Based Maximum Motor Power	25.8	Kw
Acc-Time Based Maximum Motor Power	165	Kw

As shown in table 5, the requirement of motor capacity and torque for a good launching performance is much higher than that for other requirements. In other words, most of the motor capacity is wasted in the daily-use. Therefore, a capacity trade-off design has to be taken between acceleration time and motor cost. Two potential scenarios for single reduction based BEVs powertrain are selected in this paper, scenario 1 meets all the design requirements to attain an excellent dynamic performance; Scenario 2 reduces the motor cost at the cost of a relative poor launching and overtaking ability.

TABLE 6: Motors Specifications of

Specification	Motor Scenario 1	Motor Scenario 2
Peak Power	180 kw	125 kw
Rate Power	60 kw	45 kw
Peak Torque	400 Nm	300 Nm
Rate Torque	200 Nm	150 Nm
Rated Speed	2600 rpm	2600 rpm
Max Speed	8000 rpm	8000 rpm

CVT optimization for BEV powertrain

Replacing fixed ratio single reduction with CVT will provide a feasible way to reduce the requirement of battery capacity and optimize motor operation efficiency area by a wide and continuously ratio range. Table 7 shows a typical CVT specification on market:

TABLE 7: CVT Specifications

Parameter	**Description**	**Value**
i_m	Main reduction ratio	*4*
i_{cvt}	CVT ratio varying range	*0.5~2.5*
$i_{converter}$	Torque converter ratio	*1~2.2*
η_{cvt}	CVT pulley-belt efficiency	0.9~0.95
$\eta_{converter}$	Torque converter efficiency	0~1

As an important part of CVT based powertrain for ICE vehicle, the working stages of torque converter can be roughly divided into three:

Stall: The prime mover is applying power to the impeller, but the turbine cannot rotate. At stall, the torque converter can produce maximum torque multiplication and lasts for a brief period. The efficiency is zero.

Acceleration: The load is accelerating but there still is a relatively large difference between impeller and turbine speed and it will declines accounting to the difference. The efficiency increases quickly from zero and the torque multiplication ratio drops from maximum value, e.g. 2.2 in this model.

Coupling (Lock-up): The speed of impeller and turbine are almost equivalent. The efficiency is almost 100% due to the mechanical lock between input and output shafts. There is no torque multiplication function in this period.

The economic performance of CVT heavily relies on torque converter characteristics. Figure 8&9 demonstrates the hydrodynamic and torque amplifying performance attributes of a typical torque converter.

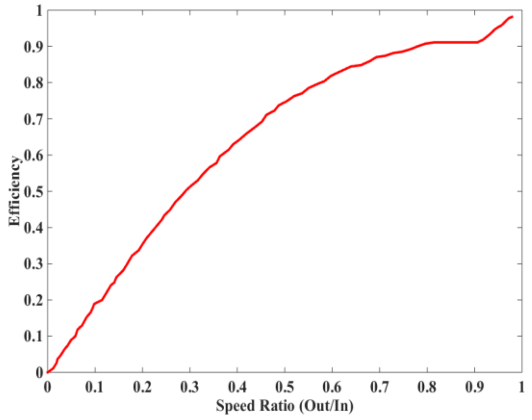


FIGURE 8: Torque Converter Efficiency

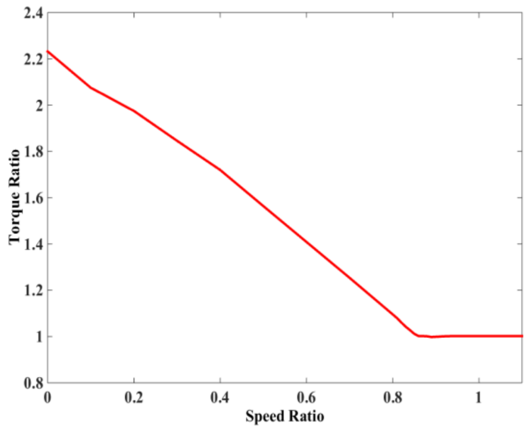


FIGURE 9: Torque Converter Torque Multiplication Ratio

The efficiency of CVT is relative to the ratio of output torque to input torque. It is presented in figure 10.

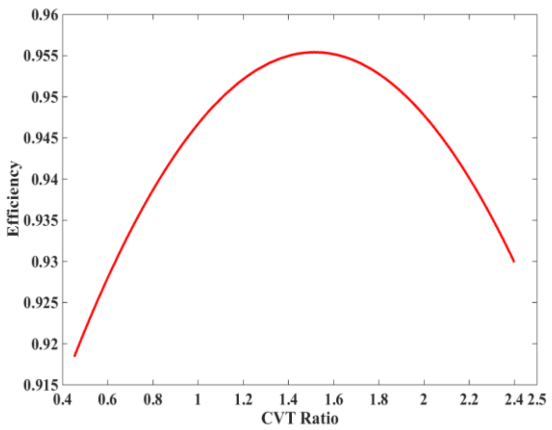


FIGURE 10: CVT Operating Efficiency

A Matlab/Simscape® torque converter model is designed to simulate the non-linear characteristics during accelerating process, which is shown in figure 10. For the hill climbing, the vehicle speed is constant, torque converter do not have the torque multiplication function, thus, $i_{converter} = 1, \eta_{converter} = 1$.

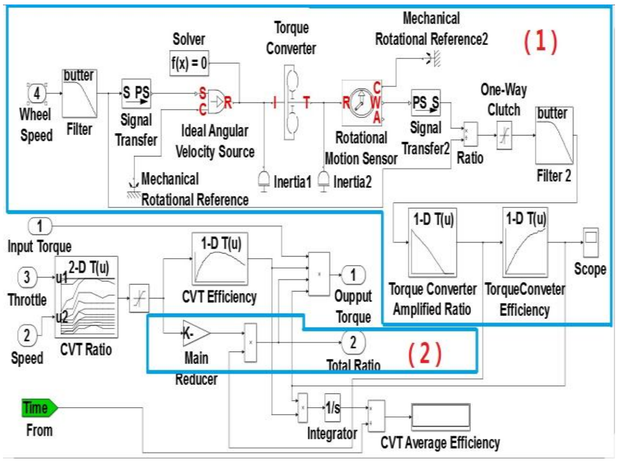


FIGURE 11: CVT Model in Matlab/Simulink®

Considering the advantage of excellent motor dynamic performance, e.g. 100% torque output ability from standstill and adjusting output torque fast and accurately during running, relative to its counterpart-ICE. Torque converter is not a necessary component for EVs anymore, which usually plays an important role in traditional vehicle to reduce vibration and avoiding ICE flameout shown in figure 11, part (1).

Aiming to attain a satisfied economic performance, the gear ratio varying schedule needs to be carefully designed in CVT control program. The efficiency of CVT is strongly influenced by the input torque, input speed and gear ratio. [12] Thereby, all these three parameters should be included in the computation of transmission efficiency and stored in a multidimensional look-up table in simulation model.

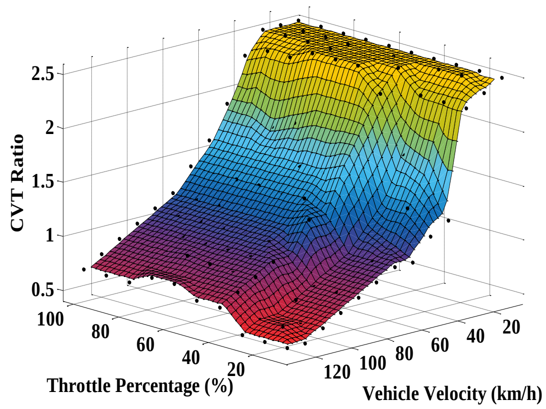


FIGURE 12: CVT Economic Shifting Schedule

For a particular vehicle speed and throttle pedal position, there is a relative most efficient point during the available motor speed range, which is determined by vehicle velocity and gear ratio range. The gear ratio, corresponding to the most efficient motor operating point, is selected as the shifting ratio on this particular condition. And by this analogy, the economic shifting schedule of CVT on EVs is achieved and demonstrated in the figure 12.

Economy Performance Comparing of CVT and Single Reduction based BEVs

To compare the dynamic and economic performance, the motors used in single reduction scenario 1&2 are retained in CVT based EV model. The efficiency maps of these two motors, presented in figure 13, are applied in the Simulink model to show the motor operating tracks in particular driving cycles.

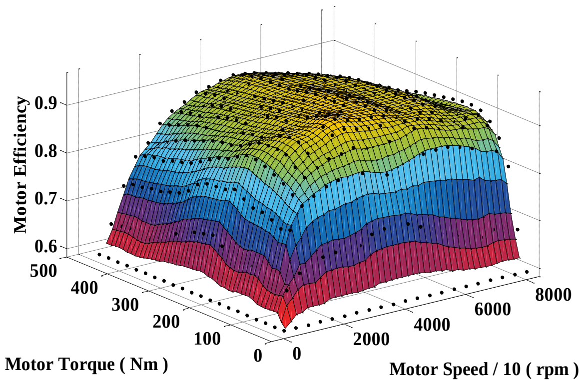


FIGURE 13 (a): Motor scenario 1 Efficiency Map

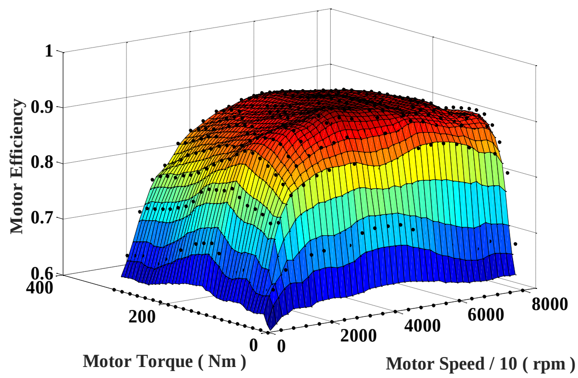
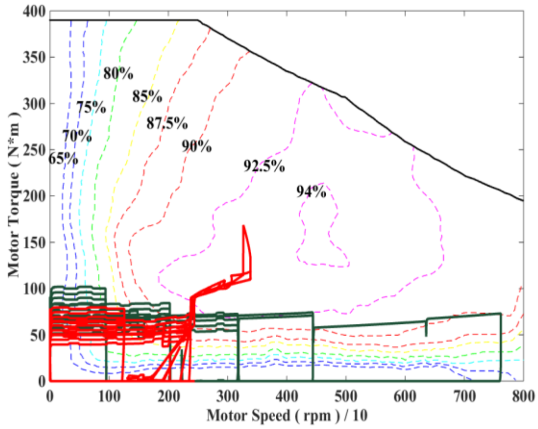


FIGURE 13 (b): Motor scenario 2 Efficiency Map

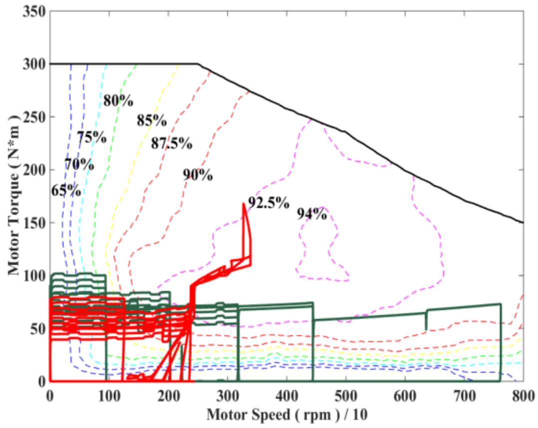
New Europe Driving Cycle (NEDC) is selected as a standard testing cycle in this paper. The dark green and red lines in figure 13 (a) shows the motor 1 operating tracks in NEDC equipped with fixed gear ratio single reduction and CVT respectively.

To meet the requirement of excellent launching and overtaking performance, most of the torque and power ability in motor 1 are spare and wasted in the daily driving, although CVT based powertrain has a better economic performance.



(a) Motor 1 cooperates with single reduction and simplified CVT

A smaller motor size in scenario 2 helps both single reduction and CVT based powertrain work more efficiently, at the expense of a relative poor launching and overtaking performance.



(b) Motor 2 cooperates with single reduction and simplified CVT

FIGURE 14: Motor Operating Points on Efficiency Map

Comparing the figure 14 (a) and (b), with the help of larger gear ratios range in CVT, motor can work more efficiently and save energy in daily-use, comparing to single reduction based powertrain, especially for high speed situations. Tables 8 present the average motor efficiency and energy consuming, in terms of SOC, in one NEDC cycle for four different powertrain based scenarios.

TABLE 8: Simulation Results

	Motor 1 + SR*	Motor 2 + SR*	Motor 1 + CVT	Motor 2 + CVT
Average Motor Efficiency	74.3%	76.5%	76.8%	78.4%
Energy Consumed (SOC)	12.4%	12.0%	11.6%	11.5%

*SR: Single Reduction

Cost and Potential Benefits Calculation

It is hard to say if the simplified CVT is a better choice for BEV's powertrain before knowing the additional cost, although it improves the dynamic and economic performance simultaneously.

According to the report from OAK Ridge National Laboratory, the basis of vehicle parts cost calculation is summarized in table 9. [13]

TABLE 9: Vehicle parts cost calculation basis

Vehicle Component	Cost (US $)
Battery	$ 400/kwh
Battery Manage System	$ 400/kwh
Motor	$ 40/kw
Transmission	$ 12.5/kw (motor kw)
Electricity	$ 0.5/kwh

In one NEDC cycle, based on the simulation result in the table 8, the energy save by simplified CVT, comparing to single reduction based EV is:

Scenario 1:

$$\text{Batv} * \text{Batc} * (12.4\% - 11.6\%) = 0.219\ (kwh)$$

Scenario 2:

$$\text{Batv} * \text{Batc} * (12.0\% - 11.5\%) = 0.137 (kwh)$$

One NEDC cycle is around 10.8 km. Therefore, 100 km design driving range equals 9.25 iterations. The design battery capacity can be reduced:

Scenario 1:

$$\text{Batc}_{save\_100km} = 0.219 * 9.25 = 2.03\ (kwh) \quad (14)$$

Scenario 2:

$$\text{Batc}_{save\_100km} = 0.137 * 9.25 = 1.27\ (kwh) \quad (15)$$

At the viewpoint of vehicle lifetime maintenance cost, CVT based BEV show a greater advantage than that in initial manufacturing cost. The estimated lifetime mileage for passenger car is 300000 kilometres. [14]

Scenario 1:

$$\text{Batc}_{save\_lifetime} = 2.03 * \frac{300000}{100} = 6090\ (kwh) \quad (16)$$

Scenario 2:

$$\text{Batc}_{save\_lifetime} = 1.27 * \frac{300000}{100} = 3810 (kwh) \quad (17)$$

The single reduction is not really a transmission system, referring to the definition on traditional vehicle. If the data in table 11 is used to estimate the price of single reduction, the price will be same to that of CVT based on same motor size. Obviously, it is not reasonable and the cost of single reduction should be much cheaper.

Therefore, a relative sales price (RSP) evaluating method of transmission system is selected in this paper. The cost of a gearbox is proportional to its weight at the first approximation.[21] The mass of transmission m_G can be related to the input torque T_1, the maximum ratio $i_{G,max}$, and the number of gears z, shown in equation (15).

$$RSP = 0.035 \times (i_{G,max} \times T_1)^{0.45} z^{0.225} \qquad (18)$$

The reference is a 5-speed automatic transmission, the maximum input torque and gear ratio are 200 Nm and 3.85 respectively. In this paper, $T_1 = 300 \text{ or } 390\ \text{Nm}$, $i_{G,max} = 7.5\ and\ 10$ and $z = 1\ and\ 6*$ for single reduction and CVT respectively. Thus, the estimated relative gearbox selling prices are presented in table 10.

TABLE 10: Estimated relative gearboxes selling price

Motor	Motor 1		Motor 2	
Transmission	SR	CVT	SR	CVT
RSP	1.27	2.16	1.13	1.92

*The selling price of CVT is estimated to be similar with a 6-Speed Automatic Transmission

Considering the cost of single reduction is much cheaper than that of CVT, the manufacturing cost of single reduction is assumed to the estimated price above to insure the price difference is big enough to testify if the simplified CVT has the ability to make up the cost disadvantage through saving battery energy.

Scenario 1:

$$Price_{cvt} = 180 * 12.5 = 2250\ (\$)$$

$$Price_{SG} = 2250 * \frac{1.27 * 0.5}{2.16} = 661\ (\$)$$

$$Cost_{increased} = 2250 - 661 = 1589\ (\$) \quad (19)$$

Scenario 2:

$$Price_{cvt} = 125 * 12.5 = 1563\ (\$)$$

$$Price_{SG} = 1563 * \frac{1.27 * 0.5}{2.16} = 459\ (\$)$$

$$Cost_{increased} = 1563 - 459 = 1104\ (\$) \quad (20)$$

Table 11 presents the manufacturing cost and daily-use energy cost save by CVT, comparing to single reduction based powertrain, with two different motor size.

TABLE 11: Manufacturing cost saved by CVT

Vehicle Component	Cost Saved with Motor 1	Cost Saved with Motor 2
Battery (100km NEDC)	$ 812	$ 508
Battery Manage System	$ 812	$ 508
Transmission (125/45 kw)	-$ 1589	-$ 1104
Life Time Fuel Energy Save	$ 3045	$ 1905
Total Save	$ 3080	$ 1817

Due to the cost saved in battery and increased cost for a more complex transmission system are almost same, there is no significant initial manufacturing cost different, after replacing the single reduction with CVT in two different motor based powertrain. Simplified CVT boosts the economic performance in both powertrain systems at the viewpoint of life-long using. CVT based powertrain has a better performance when it cooperate with a bigger size motor, though much more power is wasted in most driving conditions. However, it doesn't mean a bigger and more expensive motor is a better choice when customer cares more about cost rather than performance.

Scenario 1:

$$Price_{motor} = 180 * 40 = 7200\ (\$) \quad (21)$$

Scenario 2:

$$Price_{motor} = 125 * 40 = 5000\ (\$) \quad (22)$$

According to the equations (21) and (22), motor 1 is $ 2200 more expensive than motor 2, in the meantime, CVT just save 3080-1817=1263 ($) in the life-long time.

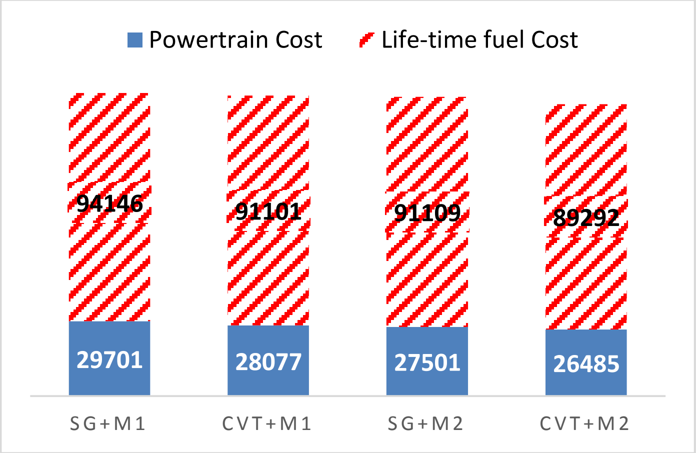


FIGURE 15: Powertrain manufacturing and daily-use fuel cost ($)

Conclusion

In this paper, a simplified CVT based powertrain system for EVs in has been validated that it not only improves vehicle dynamic performance, but also significantly reduces manufacturing and daily use cost, thanks to the wider available gear ratios range and effective CVT shifting schedule. Two propelling motors are selected to attain excellent dynamic and economic performance separately. The simulation results show that CVT help is more efficient, comparing with single reduction based powertrain, when cooperating with a more powerful motor. However, at the viewpoint of total cost in the life-time using including initial purchasing and daily maintenance fees, the cost saved in stronger motor based powertrain will not make up the initial price difference, comparing to a smaller and eco motor. In other words, the combination of eco motor and simplified CVT is the best choice to save more money, in the meanwhile, at the expense of a pooler launching and overtaking ability.

In future work, the analysis of regenerative brake via CVT should be added to model, which will result in a more precise energy consuming and cost saving prediction.

Reference

[1] Ren, Q., Crolla, D., & Morris, A. (2009). Effect of transmission design on electric vehicle (EV) performance. *Vehicle Power and Propulsion …*, 1260–1265.

[2] Zhu, B., Zhang, N., Walker, P., Zhan, W., Zhou, X., & Ruan, J. (2013). Two-speed DCT electric powertrain shifting control and rig testing. Advances in Mechanical Engineering, 2013. doi:10.1155/2013/323917

[3] Patel, D., Ely, J., & Overson, M. (2005). CVT Drive Research Study. SAE International. doi:10.4271/2005-01-1459

[4] Srivastava, N., & Haque, I. (2009). A review on belt and chain continuously variable transmissions (CVT): Dynamics and control. Mechanism and Machine Theory, 44(1), 19–41. doi:10.1016/j.mechmachtheory.2008.06.007

[5] Mäder, K. M. (2005). Continuously Variable Transmission : Benchmark , Status & Potentials (pp. 1–30).

[6] Lee, H; Kim, H. (2014). Improvement of fuel economy by shift speed control for a metal belt continuously variable. Proceedings of the Institution of Mechanical Engineers, 216(9), 741.

[7] Bonsen, B., Steinbuch, M., & Veenhuizen, P. a. (2005). CVT ratio control strategy optimization. 2005 IEEE Vehicle Power and Propulsion Conference,227–231. doi:10.1109/VPPC.2005.1554561

[8] Sorniotti, A., Subramanyan, S., Turner, A., Cavallino, C., Viotto, F., & Bertolotto, S. (2011). Selection of the Optimal Gearbox Layout for an Electric Vehicle, 4(1), 1267–1280. doi:10.4271/2011-01-0946

[9] Mäder, K. M. (2005). Continuously Variable Transmission : Benchmark , Status & Potentials (pp. 1–30).

[10] Galvagno, E., Velardocchia, M., & Vigliani, a. (2011). Analysis and simulation of a torque assist automated manual transmission. Mechanical Systems and Signal Processing, 25(6), 1877–1886. doi:10.1016/j.ymssp.2010.12.014

[11] Dr . Gerhar d Wagner and Her iber t S cherer. (2006). ZF 6-Speed Automatic Transmissions : Fuel Efficiency And Contribution To Environmental Protection. Drive System Technic, 8244, 2–3.

[12] Hofman, T., Steinbuch, M., van Druten, R., & Serrarens, a. (2009). Design of CVT-Based Hybrid Passenger Cars. IEEE Transactions on Vehicular Technology, 58(2), 572–587. doi:10.1109/TVT.2008.926217

[13] OAK RIDGE NATIONAL LABORATORY. (2010). PHEV Value Proposition Study Final Report (p. 218).

[14] Lu, S. (2006). Vehicle Survivability and Travel Mileage Schedules. Security, (January), 40.

[15] Naunheimer, Harald; Bertsche, Bernd; Ryborz, Joachim; Novak, Wolfgang; Kuchle, A. (2010). Automotive Transmissions : Fundamentals, Selection, Design and Application (2nd ed.). Springer Berlin Heidelberg.