ANALYSIS OF CVT AS TRANSMISSION IN BEV & HEV

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ABSTRACT

Battery electric vehicle and hybrid electric vehicle are coming out as a practical solution in the urban driving conditions, by reducing emission. Electric vehicles are of different types, according to the different layout of engines and the different types of transmission used. Electric motor is either a primary source or secondary source of power in battery electric vehicle and hybrid electric vehicle. In the condition of Hybrid electric vehicle, an internal combustion engine is also used. Electric motor has better torque characteristics than internal combustion engine even at zero speed. It was observed that, generally the battery electric vehicle use single speed transmission. Prius by Toyota reduced fuel consumption greatly, and at the same time also maintained the driving comfort by the use of eCVT, which is only for hybrid electric vehicle. Many electric vehicles use single fixed ratio transmission like Leaf by Nissan; Tesla's starting model and iMIEV by Mitsubishi because of the cheap manufacturing cost, light weight drive-train and smaller power-train volume. This paper gives a brief analysis on the use of CVT in EV and HEV and their effect on the range of the vehicle.

KEYWORDS: CVT, Transmission, BEV, HEV & eCVT

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1. INTRODUCTION

Battery electric vehicle and hybrid electric vehicle are coming out as a practical solution in the urban driving conditions, by reducing emission. Electric vehicle are of different types according to the different layout of engines and the different types of transmission used. Electric motor is either a primary source or secondary source of power in battery electric vehicle and hybrid electric vehicle. In the condition of Hybrid electric vehicle, an internal combustion engine is also used. Electric motor has better torque characteristics than internal combustion engine even at zero speed. It was observed that, generally the battery electric vehicle use single speed transmission 123. Prius by Toyota reduced fuel consumption greatly, and at the same time also maintained the driving comfort by the use of eCVT, which is only for hybrid electric vehicle. Many electric vehicles use single fixed ratio transmission like Leaf by Nissan; Tesla's starting model and iMIEV by Mitsubishi because of the cheap manufacturing cost, light weight drive-train and smaller power-train volume. But it was seen that in fixed speed transmission, the speed and torque were compromised, which resulted in poor dynamic performance; and secondly, the efficiency curve of the motor varied with speed and torque which led to lower overall operating energy efficiency 4.

Battery electric vehicle and Hybrid electric vehicle have such great advantage in reducing the emission and low running cost, but still it is facing difficulty in commercialization because of the huge initial cost and limited range problem. To solve the limited range problem, many researchers have suggested using different multi-speed gear transmission, which could help in increasing the range of the vehicle and also give better speed-torque characteristics. Continuously, variable transmission is a technology that is maturing, and this can offer a continuously

changing gear ratio with less moving parts. It is a promising powertrain technology for hybrid vehicle. CVT are of different types, namely Spherical CVT, Belt CVT, Power-split CVT, Hydrostatic CVT, Ball-type, toroidal CVT, E-CVT, Milner CVT, Toroidal CVT. Belt and chain type CVT are the most common type of CVT used in the automobile industry. It was seen that use of continuously variable transmission with metal belt could change speed ratio continuously, according to the load and speed of the vehicle at the same time maintaining riding comfort. To make the CVT work at higher efficiency, the speed ratio is changed by adjusting the motor and engine operating points. A chain type CVT is shown in Figure 1510.

Figure 1: (a) Basic Configuration of Chain CVT; (b) Chain Structure 5.

2. LITERATURE REVIEW

Jong-Seob Won et al. researched on the parallel hybrid electric vehicle and its energy management system. In this study, continuously variable transmission was used for the parallel drivetrain. For the generated propulsive power assessment of engine, torque amount was optimised with the proposed system. This also assessed charge sustaining scheme of battery, so that the battery could maintain high level of state of charge. Torque distribution problem was developed as multi-objective nonlinear optimization problem and was solved as a single objective linear problem, to accomplish the torque distribution. The author also developed a vehicle-mode-based state of charge compensator for charge sustaining task. The above two strategy was evaluated on the basis of urban dynamometer driving schedule. The computation time was less while using the linearization formula for the torque distribution **6. Barry Powell et al.** fitted a continuously variable transmission in a parallel hybrid electric vehicle for dynamic vehicle modelling. Electric motor was present post-transmission, as shown in Figure 2: **PHEV Post-Transmission**. Main aim of the model was to show the control of the overall system, what was being dominated by the dynamics. To develop the model, empirical and analytical techniques were used. IC Engine, electric motor, hydraulic brakes, continuously variable transmission, lead-acid battery, clutch, tyre dynamics & vehicle driveline were the modelled components. Modelling of the computer control module, control mechanism, sensors and component controllers were also modelled. Matlab/Simulink was used to carry out the modelling. Platform was offered with modular model, which to help in evaluating without redesigning the model, different motors, clutches and engines on the vehicle behaviour. During the simulation the vehicle model was accelerated from 0 to 60 mph, and then it was deaccelerated to 0mph. By observing the RMP and Torque plots, we can see the effect of CVT, shown in Figure 3: **CVT Simulation, 15 %**.

Figure 2: PHEV Post-Transmission Block Diagram 7.

Figure 3: CVT Simulation, 15 %7.

From 10 to 23.5 seconds in the simulation, the engine is engaged and RPM is held constant at 4000 RPM and the throttle angle is held at 49 degrees. High power is produced by the engine at this operating region, efficiently. Within a speed range of 20 to 52 MPH, the engine could be operated by using the CVT. This helped in smooth half-shaft torque profile, resulting in better control of A/F transients and improves drivability 7. **Cheng-Ta Chung et al.** researched on the hybrid electric vehicle and the power split electronic with continuously variable transmission. It was observed that, the e-CVT was being used as a main architecture in the hybrid electric vehicles. e-CVT was proposed in a full hybrid electric motorcycle. The architecture includes an engine, planetary gear, reversible driving motor, reversible generator, one way clutch, transmission components and dual one way clutch transmission, as shown in Figure 4.

Figure 4: PDOC Motorcycle Power Train 8.

For the best output, switching between three operation modes was carried out, electric vehicle mode, engine mode and power split e-CVT mode. For evaluating the potential and feasibility of the e-CVT, it was compared with conventional rubber-belt CVT. Results show that e-CVT required battery with low capacity, which reduced the manufacturing cost and maintenance cost. Automatic lock is provided by the dual one-way clutches when required, this helps in holding the motor or engine without additional effort and has simple control. During cruise driving to achieve optimal fuel driving economy, engine driving mode is surpassed by the power split e-CVT in high and medium speed except cruising and low end speed. The superior driving performance and fuel economy of PDOC, especially compared with the conventional rubber-belt CVT system have given a positive support (maximum 32% fuel economy improvement) that, the PDOC motorcycle is worthy of further development. With the help of PDOC and e-CVT, it was observed that the fuel economy improved by 32% as well as the driving performance 8. **Paul Bowles et al.** discussed about the post-transmission parallel hybrid electric vehicle, which was fitted with a CVT. Control strategy was discussed for management of energy. Result highlighted the models of dynamic

behaviour and fuel consumption compared to the base case. IC Engine, electric motor, hydraulic brakes, continuously variable transmission, lead-acid battery, clutch, tyre dynamics & vehicle driveline were the modelled components. Modelling of the computer control, components and sensor controller and control mechanism were carried out with the help of Matlab/Simulink. With the change in recharge level and power of the engine, fuel economy was not affected. Maximum benefit was observed in engine with low power 9.

Figure 5: Hybrid Electric Vehicle Power Train 10.

Jiahui Tang et al. studied about the energy management strategy in a hybrid electric vehicle. Energy management is an important component in an HEV, and plays an important role in improving the energy efficiency, without effecting the driving performance and also improve the fuel economy. The layout of HEV is shown in Figure 5. PHEV are complex system. Parallel electric vehicle with continuously variable transmission was the main focus for energy management using model predictive control, including gear ratio optimization and torque split was the main concern. To reduce the computational time and convert in to discrete quantity in model predictive control framework, gauss pseudo-spectral method was applied. GMP in the framework of MPC helped in obtaining the optimal gear ration and torque split ratio. Simulation outcome pointed that fuel consumption was reduced and the motor operating using GPM control strategy based on MPC, high frequency. Real-time application could gain potential with the improvement in computational efficiency 10. **John M. Miller et al.** investigated on the hybrid electric vehicle's propulsion system. It was observed that much interest is being taken on the propulsion system of the hybrid electric vehicle, globally. It was also observed that the economy plays a major role, customer's preference of buying a SUV or a full size crossover, which was evidenced by the oil price in North America. 37%/year growth rate was observed in China, an emerging market, whereas, the European market is almost unaffected by hybridization. Most of the vehicle sold in Europe are diesel fuelled, accounting almost 47%, and have fuel rating nearly equal to the gasoline hybrid electric vehicle. Constant power speed was required because of fixed single mode system, to operate the vehicle over reasonable speed. Series-parallel switching configuration is good propulsion architecture, which requires single ac drive subsystem in all power split transmission 11. **Nikolce Murgovski et al.** researched about the plug-in hybrid electric vehicle, which was equipped with CVT. The main aim of the research was to optimize the control and battery dimensioning. Electric motor and the internal combustion engine have a power limit, which is estimated as concave/convex function in kinetic energy. But in power and kinetic energy, their losses are estimated as convex. A model of battery wear was presented as an example of a city bus to reduce the cost of ownership. Simultaneously, bus is dimensioned to infrastructure prevail optimal charging power was proposed. With 0.25s as the sampling time, was a moderate size for optimizing problem, chosen drive cycle. Generally, the bus are driven on long routes, optimization would take long computational time, which would be because of the numerical challenges. Numerical steps have been taking to reduce the computational time, slack variable like the braking power. For optimization, certain values of the variable constrains have been removed. In conditions when $e(t) = 1$ and $m(t) = 1$, the ICE & EM power may be zero. To make the values in the similar

range, all the variables had been scaled. The problem was written in sparse matrix form for pre-processing. CVX was allowed to decide in the problem sparseness **12. W. Ryu et al.** investigated on the use of CVT clutch system. CVT was used in a hybrid electric vehicle; the performance of use of CVT was evaluated. Vehicle performance was analysed at the restart, with the help of simulation and experimentation the driveshaft delay and restart delay was investigated. For this investigation, a clutch actuator pressure control scheme was used in a HEV, metal belt CVT was adopted to improve the driving comfort and restart response shown in Figure 6. First, the dynamic model of continuously variable transmission hydraulic control system, drive train, CVT variator and clutch pack were obtained at the start of the vehicle to evaluate the performance.

Figure 6: Continuously Variable Transmission-Hydraulic System 14.

Based on the dynamic model, a vehicle performance simulator was developed in AMESim. The simulation was compared with the vehicle experimental results and validated. Clutch pressure build-up time was an important criterion, on which, the vehicle restart response depended till the time where clutch torque starts to get over the vehicle road load, found from simulation. The rate of change in the driveshaft torque evaluates the driving comfort. It was also found that the rate of change of clutch pressure at the restart was related to driving comfort. For improving the driving comfort and performance, it was necessary to compromise between the smooth rate change and fast clutch pressure build up was required **14. Jiageng Ruan et al.** studied about the battery electric vehicle. This would help estimate the product pricing and performance in relation with the design for the BEV manufacturer and researcher. It was observed that apart from the long term effect of the battery electric vehicle to the environment and the customers, commercialization was problem because of its limited driving range and high initial cost. Generally, the BEV powertrain have a fixed ratio reduction transmission. The use of multi-speed transmission instead of fixed ratio reduction transmission would improve the driving range of the vehicle, and also improve the efficiency of the powertrain in condition of a fixed battery size. To estimate the energy consumption and motor efficiency, modelling of a generic battery electric vehicle was carried out in Matlab/Simulink for single reduction, continuously variable transmission and 2-speed dual clutch transmission in a BEV to meet the performance requirement, determination of gear ratio of different transmission. For CVT and 2-speed DCT, shifting schedules were customised based on the requirement of energy saving and smooth shifting and motor characteristics. Simulation results of the 2-speed DCT, single reduction and CVT were compared through simulation; it was observed that both CVT and DCT showed betterment in economic performance under highway and urban driving cycle. At the same time, it attained better dynamic performance. 2-speed DCT showed less energy consumption and higher efficiency. The second gear in the DCT played an important role in each cycle by saving 14% battery energy. It was observed that improvement in BEV performance was seen with both DCT and CVT with an additional cost, at the same time save customers money in long term. CVT would provide better driving experience even during climbing, accelerating or shifting, whereas 2-speed DCT would save money in long term **15. Jiageng Ruan et**

al. researched on the battery electric vehicle. There was a limit in the driving range in the BEV, because of the low energy density of the battery. The popularly used single reduction gear in the electric vehicle is not able to accomplish the various ranges of functions. Different multi-speed EV powertrain had been investigated and compared, which included HWFET, FTP75, and city and highway cycle with weight factor. Diverse range of functional needs could be done by optimizing the gear ratio, without increasing the electric motor. CVT and 2-4 speed transmission, performance improvement was carried out, successfully. CVT was the best and showed best results for electric vehicle, which reduced the fabrication cost and fuel consumption. Energy utilization improved by 16.4% and 9.6% in B-class and E-class BEV with 2 speeds DCT. 3 speeds DCT improved efficiency in B-class BEV 16.

Jiageng Ruan et al. investigated on the increasing demand for battery power in the BEV. Battery has poor power density and cannot absorb enough breaking energy giving low range, and this is one of the reasons the commercialization of BEV is becoming difficult. Super capacitor-based hybrid energy storage was a promising solution for becoming a trend in the automotive industry. To increase the motors efficiency integration of multi-speed transmission were carried out. A BEV with HESS and electrified-CVT was proposed in this investigation, as shown in Figure 7. Parameters that were investigate were energy saving, dynamic performance of the BEV and the battery life. Analysis would also include the improvement of battery life, impacted by CVT via HESS. To improve the vehicle performance and energy efficiency, development of a gear ratio varying controlled strategy for electrified CVT.

Figure 7: (a) Single Reduction + Battery Powertrain (b) CVT + HESS Powertrain 17.

A comparison of vehicle performance for single speed BEV and electrified CVT was provided. It was observed that an improvement of 37.9% in energy efficiency for EV based on CVT. Though the improvement was 8.3%, for rest of the achievements are offset by the lost energy in the CVT. By adding a super capacitor to the energy storage system, the negative current in the battery regardless of the powertrain configuration was controlled. CVT showed better performance in all testing single than the single speed transmission 17. **Li Hangyang et al.** stated that the fuel economy and driving performance in a hybrid electric vehicle improves with the installation of CVT. The CVT improves the experience and economy because; it adjusts the operating points of the power source. Hybrid electric vehicle with CVT, dynamic model was utilised to find the minimum fuel consumption, state of charge and the control variable between speed ratio of CVT and torque distribution between engine and motor. With four different drive cycles, simulation was performed to verify the potency of the control strategy. From the observation, it was seen that the fuel economy improved to a great extent, which could satisfy the battery aging and the power requirement of the vehicle with instantaneous optimal control strategy. It would be useful for the CVT based HEV for real time energy management 18. **A. Yildiz et al.** examined the electric vehicle, which was equipped with

chain CVT. Examination of the basic control of chain continuously variable transmission was carried out. For a specified velocity profile, transient power request is obtained of the vehicle. CVT's speed ratio is determined after angular speed and torque are selected for the electric motor. As a reference, this speed is applied to the control unit; with the dynamics and feedback controlled of the CVT, it is controlled. Dynamic formula is used to obtain vehicle's real velocity, which includes overall system dynamics, and is then compared to the reference velocity profile. Characteristic map is used to select the angular speed, velocity profile and torque, power request is obtained. CVT ratio value is checked and recalculation of the angular velocity was carried out. Angular speed matches the torque load to provide power to the vehicle. Torque and angular speed of the motor determine the final speed ratio of the CVT. With the help of a feedback controller, the speed ratio which was implemented (as reference) was controlled. From the simulation, the real velocity is obtained and is compared with desired velocity profile. The proposed model, when compared indicated good correlation and can be reference for different control algorithm 20. **Xingda Yan et al.** researched on the CVT operated parallel pre-transmission hybrid powertrain. By optimizing the power split of the IC engine and battery, to increase the travel range without focusing on transmission system. Optimization of the continuously variable transmission was the main focus to achieve better fuel economy. Simulation was carried out for fixed transmission and optimized CVT and compared. The result showed that optimized CVT had increased range and better fuel consumption and because of which, the engine operated at higher efficiency 21. **S Gawade et al.** researched about the electric vehicles in India. In India, the environmental pollution is caused by auto rickshaw. The auto rickshaw is the main reason for pollution, because they are not serviced and maintained properly. Switching conventional rickshaw to electric rickshaw would reduce the emission problem in urban areas. CVT was preferred, because of its uninterrupted power transmission and infinite gear ratio. Motor is to run at it optimal speed with CVT, and this reduces the current consumption. The CVT could be tuned to be compatible with electric powertrain. The paper focused on the effect of CVT performance by varying the mass of flyweights. DAQ system was used to measure the driven pulley and driver pulley RPM, which was then used to acquire gear ratio. Flyweights of two different types were used to perform the iterations. At 120 grams mass of the flyweight, different speed ratios were obtained. Highest speed ratio was used to operate the CVT for every throttle position. When the mass was changed to 260 grams for the flyweights, 0.733 to 3.433 range was obtained for different speed ratios. It was concluded that the CVT designed for IC engine could be used for 1kW electric motor. This could help in reducing the urban air pollution with CVT, which were cheaper and only tuning would be required 22.

Figure 8: Speed Ratio & Actual Speed of a CVT Optimal Control Solution 18.

Jianjun Hu et al. researched on the HEV, which were equipped with continuously variable transmission. Regenerative braking strategy improvement in HEV with CVT is the main focus. Consideration is of the dynamic change on the CVT ratio for the braking effect. Motor braking and motor/engine braking were analysed. During dynamic braking

process, the required deviations arise from actual braking strength. Limitation of the ratio rate was proposed for CVT ratio control with discrete exhaustive optimization method. 32.24% and 30.31% were the maximum braking overshoot for motor only and motor/engine braking mode. In simulation analysis, it was observed that deviation between maximum braking and required could be controlled by 4%, and braking energy recovery could increase by 5.6% **23.Cheng-Ta Chung et al.** researched on the electronic-continuously variable transmission and investigated the energy efficiency of the same under energy circulation operation. To improve the efficiency of the system, energy power was circulated through the generator and the motor, which also improves the functionality of CVT. To classify the engine on the basis of rotational speed and torque, each power components relation of energy and kinematics were constructed and analysed, which varied on the degree of electric circulation indicated by ratio of circulating power. There are mainly three types of classification of e-CVT: neutral circulation, downward circulation and upward circulation. Input split type and output split type are selected from the two power split e-CVT for analysis of operating characteristics, and simulation are carried out on their energy efficiency performance. The earlier were a downward circulation type, which helps in low speed driving and high load; whereas the second one is upward circulation that helps in high speed driving and low load. For the power split e-CVT to have good energy efficiency and good performance, powertrain architecture should be capable of switching between upward and downward circulation mode **25. Boli Chen et al.** investigated on the use of continuously variable transmission in series hybrid electric vehicle. The CVT was used to connect the electric machine to the motor. The fixed transmission used till now utilizes a fixed final drive ratio, whereas variable transmission ratio is possible in CVT, which could be controlled freely that allows the motor work, efficiently. Under an optimal control framework, CVT performance was evaluated under urban driving mission. The urban driving was specified in conditions of time of journey and road geometry. Optimization of energy management system and vehicle speed was carried out through indirect optimal control method, Pontryagin's minimum principle. Through the simulation results, it was seen that there is an improvement of 3.53% in fuel economy with CVT, compared to fixed transmission **26.Qiwei Xu et al.** analysed the hybrid electric vehicle fitted with electric variable transmission. To analyse the internal magnetic field coupling law, finite element simulation and equivalent magnetic circuit was established. Strong coupling relation of the internal magnetic transmission, magnetic flux insulation ring was applied to the EVT in HEV and builds its mathematical model. Analysis of hybrid electric vehicle's working modes is attained.

Figure 9: EVT Diagram 28.

Power output of the electric variable transmission and engine depends on the power follower strategy. Change in the transmission ratio was continuous with the use of EVT as CVT. Vehicle control strategy ensured that the engine worked at high performance region, which would improve fuel economy, power and reduce emission **28.**

Figure 10: EVT as Base for HEV 28.

Jiageng Ruan et al. found that pure electric vehicle was a good alternative to conventional vehicles. In the electric vehicle, the internal engines are removed but still provide efficient energy utilization. But the electrochemical power source limits the driving range, which is relatable to battery having low energy density. This presents a major problem in large scale commercialization due to range phobia. HEV structure is shown in **Error! Reference source not found.** The diverse range of functions is not accomplished by the single reduction gear in EV, multispeed conventional vehicle like good acceleration and high speed. Comparison of a multi-speed EV powertrain (DCT and CVT) has been carried out for the application. With multiple gear ratio optimization and shifting strategy, more variation was possible without increasing the battery size and electric motor size. The different combination of cycles used for the testing was highway cycle, city cycle, FTP-75 and HWFET with weight factor. DCT with two speed showed good energy utilization in both B, E class PEV which were 16.4% and 9.6% higher than single speed PEV. But in the case of three speeds DCT, the efficiency increased in B-class PEV and in case of E-class it reduced. It was concluded from the simulation that CVT was best for customers and OEM, for every PEV vehicle class **29. M. Delkhosh et al.** developed a control strategy, which was equipped in parallel hybrid electric vehicle with Full-toroidal CVT. Baseline static control strategy was kept base and a modified control strategy was proposed. With the modified strategy, the engine was operated and it was found that fuel consumption decreased. Baseline static control strategy modification was only possible by CVT as power train. BCS and proposed control strategy were optimised in SC03 driving cycle, which were then compared. Proposed strategy was better than BCS in full toroidal, in terms of SC03 driving cycle. Vehicle FC control strategy was 16% below the optimised BCS, therefore BCS modification was beneficial. In the overdrive cycle, the optimised strategy were compared which, showed low FC compared to BCS **30. Fuad Zainuri et al.** researched on the development of a transmission, which could improve the efficiency and reduce energy consumption in electric vehicle. Expectation of the customers is convenience, safety and competitive price. For the road vehicles, continuously variable transmission, automatic transmission and dual clutch transmission are the recent technologies. It was found that manual type transmission was more successful when compared to automatic transmission, changing gear; there is large power loss in the electric vehicles due to limited power backup. Systems which could change gears in zero time are known as Zero shift, as shown in Figure 11. This gear was developed for automatic manual transmission. This type of transmission was used for the racing cars so that during gear the vehicle does not decelerate. Clutch is still used in zero transmission, but the clutch pedal is replaced by electromechanical. For electric vehicle, the transmission is too complex, but it increases the efficiency of the transmission. For improving the efficiency of the transmission, combination of synchromesh with zero shift for manual transmission was ideal. Synchromesh would replace the need of clutch in the zero shifts, and also helped in changing gear according to the motor torque. The design has an added advantage for the character of the motor. The number of gear changes would make it power efficient for various factors. To improve the performance of the electric motor, transmission weight plays an important role. Transmission in the electric vehicle will help in the problem of energy that is available, which influences the transport **31.**

Figure 11: Zero-Shift Two Gear31.

3. CONCLUSIONS

In this paper, the use of continuously variable transmission in electric vehicle and battery electric vehicle has been focused. How the use of CVT that could affect the range of the vehicle and how the battery efficiency could be affected was found. The following conclusions were made, based on the investigations carried out by different engineers and researchers:

- CVT designed for IC engine could be used for 1kW electric motor.
- When the vehicle was in a speed range of 20-52 MPH, it was seen that the engine could be operated by using a CVT. This helped in smooth half-shaft torque profile, resulting in better control of A/F transients and improve drivability
- The superior driving performance and fuel economy of planetary gear set and dual one-way clutch transmission, especially compared with the conventional rubber-belt CVT system have given a positive support (maximum 32% fuel economy improvement) that the PDOC motorcycle is worthy of further development. With the help of PDOC and e-CVT, it was observed that the fuel economy improved by 32% as well as the driving performance.
- HEV equipped with CVT simulation pointed that, fuel consumption was reduced and the motor operating using GPM control strategy based on MPC and high frequency.
- Clutch pressure build-up time was an important criterion, on which the vehicle restart response depended, till the time where clutch torque starts to get over the vehicle road load, found from simulation. The rate of change in the driveshaft torque evaluates the driving comfort.
- CVT and DCT showed betterment in economic performance under highway and urban driving cycle. At the same time, it attained better dynamic performance. 2-speed DCT showed less energy consumption and higher efficiency. The second gear in the DCT played an important role in each cycle by saving 14% battery energy. It was observed that improvement in BEV performance was seen with both DCT and CVT with an additional cost, at the same time save customers money in long term. CVT would provide better driving experience even during climbing, accelerating or shifting whereas 2-speed DCT would save money in long term
- A comparison of vehicle performance for single speed BEV and electrified CVT was provided. It was observed that an improvement of 37.9% in energy efficiency for EV based on CVT. Though the improvement was 8.3%, for rest of the achievements are offset by the lost energy in the CVT. CVT showed better performance in all testing single than the single speed transmission.
- Hybrid electric vehicle with CVT, with four different drive cycles, simulation was performed to verify the potency of the control strategy that the fuel economy improved to a great extent, which could satisfy the battery aging and the power requirement of the vehicle with instantaneous optimal control strategy.

- power split e-CVT to have good energy efficiency and good performance, powertrain architecture should be capable of switching between upward and downward circulation mode

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