Performance Analysis of Continuously Varying Transmission System for Electric Vehicles

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***Abstract*— Electric Vehicles have zero emissions and are hence green and environmentally friendly. A lot of research is being done considering such vehicles at the system level. One of the systems being worked on is CVT (Continuously Varying Transmission). In this paper, an attempt is made to incorporate a CVT system with an electric vehicle. This setup will allow the motor to operate in high-efficiency ranges and effectively bring down the power consumption of the entire system.**

Keywords— ***Electric Vehicles; Continuously Varying Transmission systems; Noise Vibration Harshness analysis; Automobiles.***

I. Introduction

The past few decades have seen a steady rise in awareness on the importance of vehicles which cause minimal pollution and utilize the lesser amount of energy. The main theme of clean technology is to minimize the dependence on fossil fuels. Renewable and green sources of energy like solar and electricity emerge as key alternatives to energy to realize a sustainable future. The rapidly fluctuating oil prices along with the massive amount of pollution have put forth a need to find an alternative operating on clean energy.

Electric vehicle (EV) sales grew 60 percent worldwide in 2015, according to Bloomberg New Energy Finance, which predicts in an article, "Here's How Electric Cars Will Cause the Next Oil Crisis," that electric vehicles will account for 35 percent of new car sales globally by 2040. Although electric vehicles have been conceived several decades ago, limitations on their range and charging issues have hindered their emergence as a primary mode of transport. In recent years, however, advances in battery technology have allowed electric vehicles to re-enter the market. This paper deals with the study of “Continuously Varying Transmission” (CVT) system, one of the cutting-edge technology currently in use with IC engine Vehicles which can be adapted to electric vehicles to allow seamless transmission. This in effect results in power savings.

II. Literature Review

It was found during the literature survey from studies conducted by Chang and Siao (2010) that incorporating transmission system in electric vehicles can reduce power requirements for the motor as well as enhance the performance of the electric vehicle. The power savings were a result of the severe drop in motor efficiency with the rise in its operational speed.

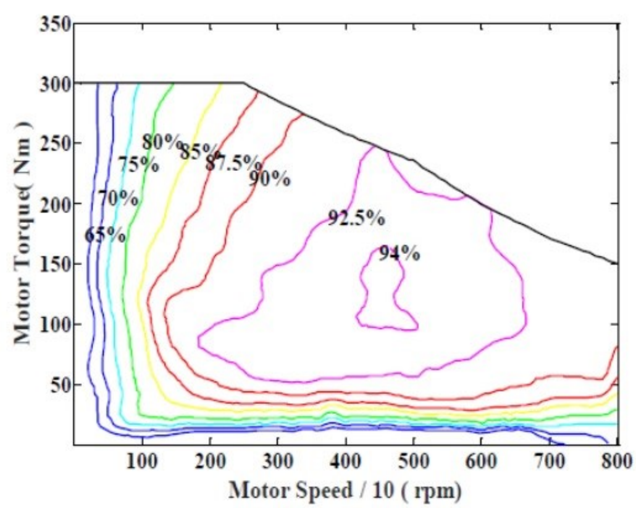

Figure 1: Motor Torque vs. Motor Speed for Efficiency Region

Upon Comparing Single reduction Transmission and Continuously Varying Transmission (CVT) on battery electric vehicle, Jiageng Ruan et al (2015) have found that incorporating a CVT system results in significant improvement on battery energy saving, range extension, and overall weight.

The system used for simulating electric motor incorporated with multi-speed transmission by Q. Ren et al (2010) has been understood in detail and applied to simulating the working of a CVT system using MATLAB.

In a comparison across all the transmission systems, CVT is known to produce very low levels of noise and vibration. Hence the current study also included a check for Noise,

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Vibration, and Harshness (NVH) of the CVT system, in line with the studies conducted by Paul and Zhang (2014).

III. PERFORMANCE SIMULATION RESULTS

The first simulation carried out was for the case without any transmission system. Using the properties of the motor, a plot of the Efficiency (vs) Torque (vs) RPM is generated.

Table 1: Motor and Tire Parameters

Sl.No	Parameters	Value
01	Type	BLDC hub motor integrated with R-10 light aluminum alloy rim
02	Voltage (V)	60V
03	Nominal power output	800 watts
04	Peak Power	1800W
05	Rim	2.15” x 10”
06	Tire	3.00 X 10 - - 4 Ply

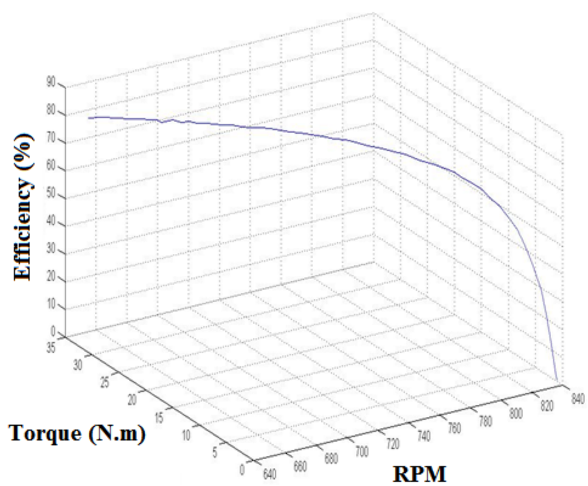

Figure 2: Direct Transmission Performance Graph

Based on torque and rotational speed, the power consumption of the system is estimated using the equation:

$$P = Fv = \frac{Tn}{9550}(Kw) \qquad (1)$$

Where T – Torque in N.m and n – Speed in RPM.

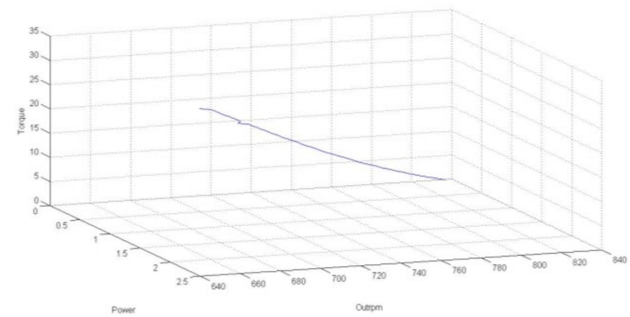

Figure 3: Direct transmission power consumption

The second simulation consisted of a continuously variable transmission (CVT) system coupled with the electric motor.

Table 2: CVT Parameters

Sl.No	Parameters	Value
01	Gear ratio	0.5 to 1.9
02	Type	Continuous varying planetary type

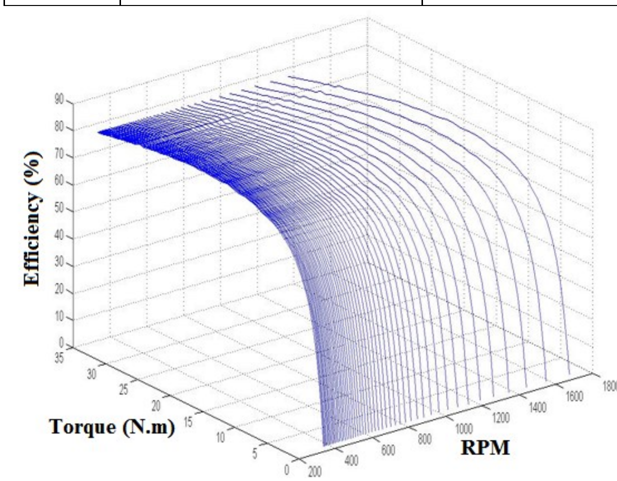

Figure 4: CVT Performance Graph

CVT allows for a sequence of paths (by varying gear ratio) which can be followed by the vehicle. On the other hand, it is seen that in figure 2 there is only a single path available for the performance to follow. By coupling the CVT system with a controller capable of changing gear ratios to suit the requirement, the performance can be maintained in the high-efficiency region.

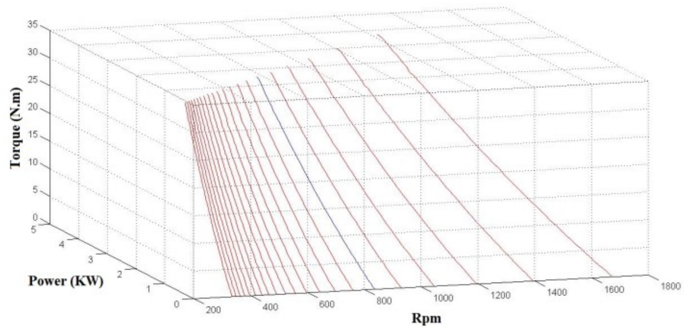

Figure 5: CVT Performance Graph

The validation of this analysis is done through experimental analysis. The vehicle was run on a definite vehicle path and the resulting current values were recorded. The experiment is performed for both the cases and a comparison has been drawn.

IV. NOISE AND VIBRATION SIMULATION RESULTS

A simplified structure of the CVT without torque converter is modeled using NX CAD and later Harmonic analysis is performed using NX Nastran and Ansys in order to predict the Noise Vibration and Harshness (NVH) behavior. During the constraint-based modal analysis, the first critical natural frequency of the system is observed to be 99.328 Hz.

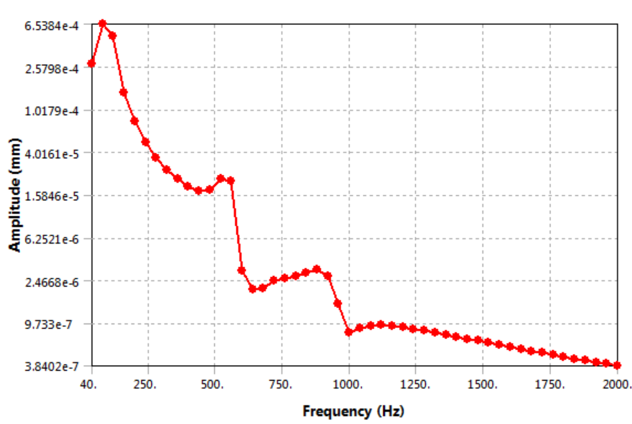

Figure 6: Displacement (mm) v/s Frequency (Hz)

Utilizing the results of harmonic analysis, the sound levels generated by this system have been found to be as shown in figure 7.

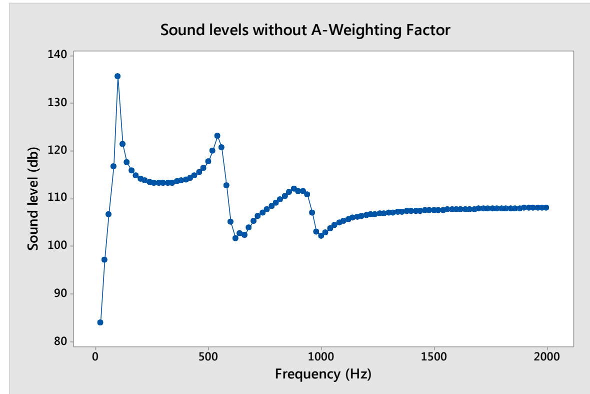

Figure 7: Sound Levels (dB) v/s Frequency (Hz)

Since bare minimum mechanical elements are being used during analysis, the CVT mounted within the entire system will produce less noise. This study, however, indicates us that in comparison with other types of transmission systems like planetary Gears, CVT produces lesser noise. Figure 8 confines the sound levels after considering suitable A weighting factors.

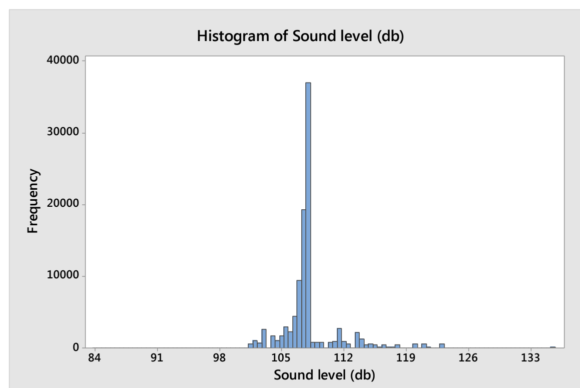

Figure 8: Histogram of Sound Levels (dBA) v/s Frequency (Hz)

V. EXPERIMENTAL ANALYSIS

To arrive at conclusions clearly indicating the power consumption value differences between the two cases, experimentation has been carried out on an electric vehicle equipped with a CVT system.

Figure 9: Electric vehicle mounted with CVT system.

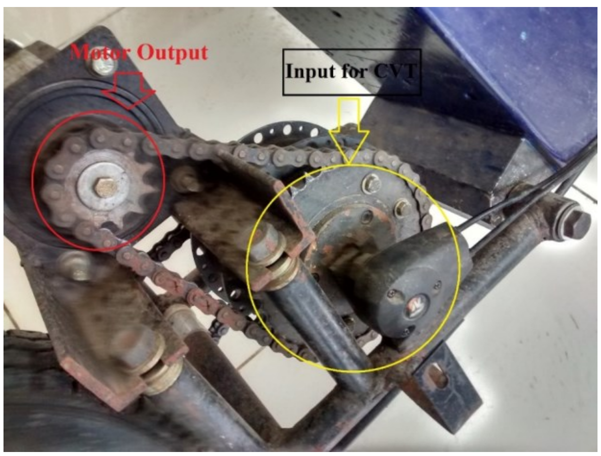

Figure 10: Motor-CVT chain drive

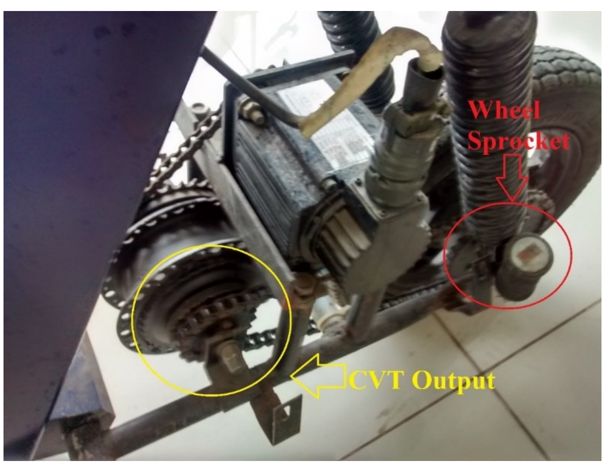

Figure 11: CVT-Wheel Chain drive.

Prior to conducting the experiments, a Design of Experiments table has been set up. Using the indicated sequence, the results have been tabulated and utilized for regression analysis.

Table 3: Design of Experiments (DOE) Table and measured quantities.

Input RPM	Gear Ratio	Measured Current	Output RPM
200	0.5	9.5	96
200	1.5	11.5	400
667	1.5	13.6	1194
667	0.5	10.5	340

Regression analysis is used to predict the output value along with a suitable relation between inputs. The regression equation is shown as a part of table 4 below.

Table 4: Results of Regression analysis.

Regression Equation : Current = 7.614 + 0.003297 RPM + 1.869 Gear Ratio
(R square =91.71%%)

Input RPM	Gear Ratio	Measured Current	Output RPM	Predicted Current	% Difference
200	0.5	9.5	96	9.1245	5%
200	1.9	11.5	400	11.9739	-6%
667	1.9	13.6	1194	13.02434	7%
667	0.5	10.5	340	10.87494	-5%

It must be noted that the regression equation is predicting our current values with an accuracy of around ± 6%. To validate these results, three trial runs have been done with intermediate input values.

Table 5: Measured values of Trial runs.

Input RPM	Gear Ratio	Measured Current	Output RPM
350	0.87	10.3	200
550	0.87	11	356
400	1.43	11.8	530

Using the input values from Table 5, the output values are predicted by using the regression equation generated in Table 4. The results are tabulated in Table 6.

Table 6: Prediction of current values for Trial runs.

Regression Equation :
Current = 7.614 + 0.003297 RPM+ 1.869 Gear Ratio
(R square =91.71%%)

Input RPM	Gear Ratio	Measured Current	Output RPM	Predicted Current	% Difference
350	0.87	10.3	200	10.69627	-5%
550	0.87	11	356	11.36027	-4%
400	1.43	11.8	530	11.48203	5%

Hence, it is observed that the regression equation is capable of predicting output current value with ± 6%. To further improve the accuracy, we incorporate the data acquired from trial runs and recalculate the regression equation.

Table 7: Optimized Regression equation.

Regression Equation :
Current = 7.614 + 0.003297 RPM+ 1.869 Gear Ratio
(R square =96.71%%)

Input RPM	Gear Ratio	Measured Current	Output RPM	Predicted Current	% Difference
200	0.5	9.5	96	9.2245	3%
200	1.9	11.5	400	11.7739	-2%
667	1.9	13.6	1194	13.32434	2%
667	0.5	10.5	340	10.77494	-3%
350	0.87	10.3	200	10.39627	-1%
550	0.87	11	356	11.06027	-1%
400	1.43	11.8	530	11.58203	2%

This semi-empirical equation predicts the results with a higher accuracy of about ± 3%. This equation is, therefore, suitable for accurately predicting the current output. This analysis allows us to avoid the need for further experimentation to determine the intermediate current values.

The equation hence generated is utilized to conduct a comparison analysis between a system with and without CVT. Power value is computed by multiplying the current with voltage. For the case without CVT, the gear ratio is fixed at 1 to simulate a direct drive situation. For case without CVT, the gear ratio is controlled to provide maximum efficiency. Torque requirement is kept constant for both cases.

For the case of without CVT, it was seen that there is a steady increase in power value from 10.1424 KW to 11.659 KW. In the case of with CVT, controlling the Gear ratio allows us to maintain the power values between 9.2738 KW and 9.6034 KW for the same drive conditions. These results indicate that by altering the gear ratio using CVT, the motor is able to operate at speeds which prove to give higher efficiency.

VI. CONCLUSIONS

By performing numerical simulation along with experimental analysis, it was observed that use of infinitely variable transmission systems like a Planetary type CVT is beneficial for electric motors. It brings down their power consumption by allowing the motor to operate in a high-efficiency speed range. Across the available CVT systems, planetary type CVT is preferred due to its quiet and smooth operation.
Using a CVT system has an impact on improving the overall efficiency of the electric vehicle. It also causes the motor to operate in its most efficient region which is also safe for the motor itself. This leads to extending the life of the motor.
Application of CVT systems is not limited to automobiles. They can be incorporated into scenarios where the motor faces rapid variations in torque requirements, for example, electric wheelchairs. Using CVT systems will allow electric wheelchairs to easily climb steep slopes like hospital ramps, extend the battery life and at the same time extend the life of the motor too. Under future scope, studies are planned to couple existing systems of CVT and electric wheelchairs to check for compatibility and validate the benefits.

VII. REFERENCES

[1] Amir Khajepour, Saber Fallah, Avesta Goodarzi, Electric And Hybrid Vehicles, John Wiley & Sons Ltd, 2014

[2] Chang Chih-Ming, Siao Jheng-Cin, "Performance Analysis of EV Powertrain system with/without transmission", World Electric Vehicle Journal, Vol. 4 - ISSN 2032-6653, 2010

[3] D. Rockwood , N. Parks , D. Garmire , "A continuously variable transmission for efficient urban transportation", Sustainable Materials and Technologies, 1–2 (2014) 36–41

[4] E. Maleki Pour, S. Golabi, "Design of Continuously Variable Transmission (CVT) with Metal Pushing Belt and Variable Pulleys", International Journal of Automotive Engineering, Vol. 4, Number 2, June 2014

[5] Jiageng Ruan, Nong Zhang, Paul Walker, "Comparing of single reduction and CVT based transmissions on battery electric vehicle", The 14th IFToMM World Congress, Taipei, Taiwan, October 25-30, 2015

[6] M. Pasquier, "Continuously Variable Transmission Modifications and Control for a Diesel Hybrid Electric Powertrain", 04CVT-57, SAE International, 2004

[7] Mir Saman Rahimi Mousavi, Ali Pakniyat, Tao Wang, Benoit Boulet, "Seamless dual brake transmission for electric vehicles": Design,control, and experiment, Mechanism and Machine Theory 94 (2015) 96–118

[8] Paul D. Walker, Nong Zhang, "Active damping of transient vibration in dual clutch transmission equipped powertrains: A comparison of conventional and hybrid electric vehicles", Mechanism and Machine Theory, 77, (2014), 1–12