Cost Analysis for Conversion of Conventional Vehicle into Plug-In Hybrid Electric Vehicle

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Abstract

Electrical vehicles (EVs) are gaining more attention due to its environmental friendly approach. However, growth is limited by consumer mindset and its high initial cost in developing countries. In a country like India, the majority of the vehicle running on the road are fossil fuel based and it does not comply with emission norms. Conversion of the conventional vehicle (CV) into the plug-in hybrid electric vehicle (PHEV) is promising option to reduce environmental impact of present vehicles running on the road towards sustainable transportation. However, limited by conversion complexity and economics. The paper discusses costing trends of electric powertrain components and cost analysis for conversion. A diesel engine car converted to parallel PHEV is used for study with 70 bhp engine for 60 km range. In-depth cost analysis is presented for conversion. Two different scenarios are considered for calculation with a current and futuristic timeline and its implications are presented in detail.

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1 Introduction

EV is more promising in reducing emissions. EV sales are still at a very nascent stage in India. The Government of India has announced an ambitious target of all-electric vehicle sales by 2030. However, IC engine-based vehicle sales is dominating. Indian auto manufacturers produced a record 29.1 million motor vehicles in 2017–18 (Apr–Mar) incl. 4.01 million passenger vehicles [1]. Costing of EV and PHEV available is very high for similar performance of IC engine vehicles. Infrastructure development is another challenge and it will take long time to go towards dominating electric car market [2]. Irrespective of development of advance fuel and alternative fuel technology, the dominating IC engine vehicles pollute the atmosphere. Pollution is not observed to be in control. 154 out of 168 cities in India does not comply with World Health Organization (WHO) and National Ambient Air Quality (NAAQ) standards [3]. To reduce the environmental influence of present vehicles running on the road, conversion of CV into PHEV is one of the promising options. It can be charged from standard outlets available at home and hence separate infrastructure is not necessary. However, there is less attention in terms of conversion of CV into PHEV as few papers are observed in literature related to the conversion of CV into HEV/PHEV, conversion of HEV to PHEV and converted HEV/PHEV [4–18]. Most of them are related to conversion, energy management strategies with concerns of fuel economy and reduction of emissions. Only two papers discussed on the costing first: economic consideration of converting a Chicago Transit Authority (CTA) transit bus to a PHEV is carried out [17] with the payback result of 5 years for the conversion and second, financing of EV conversion based on voltage system needed for conversion are studied in [18]. There is no guideline which will give costing sense for conversion of conventional vehicle to plug-in hybrid electric vehicle. Since economic consideration is one of the major aspects to shift from IC engine technology towards more electrified vehicle and there is no contribution on costing and analysis for conversion. There is a need to investigate on costing and provide in-depth cost analysis for conversion of CV into PHEV. Also, clarity in conversion costing will provide motivation to shift from IC engine technology towards more electrified vehicle for sustainable transportation. The aim of the paper is to provide in-depth cost analysis for conversion of conventional vehicle to plug-in hybrid electric

vehicle. In addition, costing trend of electric powertrain are discussed in detail. The paper is organized as below.

Section 2 deals with costing trends of electric power train (battery, power electronic converter and motor). In Section 3 costing details for conversion is presented along with analysis considering current and future costs as per cost trends. Finally, results are discussed, followed by a conclusion.

2 Costing Trends of Electric Powertrain

The electric power train cost composed of energy storage (battery), power electronics converter (PEC), motor drive and controller as shown in Figure 1. It is observed that highest cost of 55% is of battery followed by power electronics components of 24%.

Figure 1 Cost of Powertrain Components [19].

The costing of the electrical powertrain is decided by the cost of energy storage battery.

2.1 Battery

As per BEG-USA, the most promising battery automotive technology is Lithium (Li). The variations are lithium nickel cobalt aluminum (NCA), Lithium nickel magnesium cobalt (NMC), lithium titanate (LTO) and lithium iron phosphate (LFP). The technology which is more prevalent in consumer application is lithium cobalt oxide which is unsuitable for automotive application because of its inherent safety risk. The details can be seen from Figure 2.

Figure 2 Li-Ion Technology [20].

However, Li-ion battery has uncontrollable thermal spikes due to exothermic run-away reaction and engineered solutions may not arrest thermal event once it is established.

It can be seen that NCA is better in specific power and energy, however, limited due to safety and cost. LMO has an average performance with the limitation of less life span. LFP and LTO are best in lifespan and safety, however, specific energy is very low in both variants and LTO is costlier. NMC has average performance and better in all aspects as seen in Figure 2. The comparison of future lithium variation is shown in Figure 3.

Figure 3 Comparison of Future Lithium Air with Li-Ion and Lead Acid [21].

It can be seen from Figure 3 that in future lithium-air technology may have a range of more than 600 km compared to 180 km of current Li-ion technology and around 80 km of the lead-acid battery. However, the challenges of a lithium-air are safety and lifetime (especially over cycles).

NiMH batteries are also in the race for propulsion applications as more than 10 million hybrid electric vehicles currently on the road are powered by NiMH batteries [22]. Performance of a NiMH is shown to be superior [23]. According to BASF [24], NiMH batteries will have 10 times more energy density. Also, NiMH batteries has no thermal spikes and are intrinsically safe. The thermal rise is easily detected and easily controlled by the termination of charge. The other technology highlighted are

PbO₂ – Lead dioxide
 NiCd – Nickel Cadmium
 NaNiCl – Sodium Nickel
 Chloride – (Zebra)
 NaS – Sodium Sulphur

Battery technology required for PHEV is unavailable in developing countries like India. Hence, international costing trends are studied and used to perform a cost analysis for conversion of CV into PHEV. The costing trend shows that the cost of battery declines by 77% from the year 2010 to 2016.

Figure 4 Battery Pack Price trends in ₹/kWh [25] (\$–Indian rupee/INR and 1 \$ = 80 ₹).

Currently, the battery is available at the price of 11200 ₹/kWh and predicted it would come down to 8000 ₹/kWh by 2020 [26]. The current status of requirement of energy storage device technology for variations of electric vehicles is plotted as a Ragone plot in Figure 5.

Figure 5 Ragone Plot Comparing Power and Energy Densities of Battery Technologies [27].

Ragone plot indicates the performance with respect to power density and energy density. Lithium batteries along with Zebra and NiMH are competent for variants in EV as seen in Figure 5. In addition, ultracapacitor which has high power density can be used in combination with battery technology for regenerative braking and assistance during high acceleration to improve the life of the battery.

2.2 Power Electronics Converter (PEC)

At the component level, the electrical propulsion system of an electric car controls off-the-shelf power electronics, including inverter or converter components, which were initially designed for high-volume applications. This approach helps automotive suppliers to reduce costs. However, the automotive power electronics context also comes with unique design and

Figure 6 Costing of PEC [28].

manufacturing benchmark challenges for suppliers. The costing of power electronics converter is shown in Figure 6.

It is observed that the cost of power electronics switches and PCB each account 25% of the total followed by the capacitor of 16%.

2.3 Motor

The main choice in the electric powertrain design is the type of motor and controller to use. The types of motors are being seriously considered are Permanent Magnet Synchronous Motor (PMM) and Induction Motor (IM). Around 83% of motor used for electric propulsion are synchronous followed by 13% of asynchronous [29]. There is a lot of research going on variants of reluctance motors. The costing target of the electric traction drive system can be seen in Figure 7.

The R&D portfolio is focused on technology development rather than system development. As a result, towards the target of 640 ₹/kW, the target of 960 ₹/kW has been achieved. As the production volume increases the costing reduces drastically.

Figure 7 Required Technology Shift to Achieve Cost Target for Electric Traction Drive System (ETDS) [29].

3 Cost Analysis for Conversion

The specification and parameters of vehicle considered for the study are shown in Table 1 [30].

Table 1 Vehicle specification and parameters

Weight	1045 kg
Engine type	4 Cylinder Turbo Intercooled
Displacement	1405 cc
Fuel type	Diesel
Maximum power	70 bhp @ 4500 RPM
Maximum torque	135 Nm @ 2500 RPM
Mileage (AR/AT)	19.1 kmpl
Frontal area	2.12m ²
Gear ratio	3.42:1.95:1.13:0.74:0.636
Differential ratio	3.73:1
Radius of tire	0.2876 m
Coefficient of rolling resistance	0.015
Air drag coefficient	0.185
Gradient	15%

(Continued)

Table 1 Continued

Electric Powertrain Parameters	
Battery capacity	22.6 kWh
Motor capacity	15.78 kW
Base speed	60 km/hr.
Range/charge	60 km
Acceleration	1.667 m/s ² (0–60 km/hr.)
Weight	200 kg.
Assumptions	
SOC range	70%
Motor efficiency	0.9
Transmission efficiency	0.9
Battery efficiency	0.9
Efficiency	0.729

3.1 International Market Costing Trends

The costing trends for various electric powertrain components are plotted in Figure 8 (data obtained from [31]). The current and targeted costing of the battery as an energy storage device, PEC and two motors PMM and IM comparison are shown in ₹/kWh on timeline 2017 to 2030.

Figure 8 Costing Trends of Electric Powertrain from 2017–2030 [31].

The details of component capacities and costing considered for study can be seen in Table 2.

Table 2 Costing of Components for Conversion

Components	Capacity				2017	2020	2030	Unit
	Standard* Condition		Actual					
Battery	12.7	kWh	22.6	kWh	14,080	13,200	11,280	₹/kWh
PEC	15.875	kW	28.45	kW	360	240	200	₹/kWh
Charger	Standard				20,000	15,200	10,000	₹
Permanent Magnet Motor (PMM)	14.2	kW	15.78	kW	1032	800	800	₹/kW
Induction Motor (IM)	14.2	kW	15.78	kW	824	640	640	₹/kW
Other including Labor*	* 1% per annum per month rise in charges				240	247.2	271.2	₹

* Standard-Ideal condition as per manufacturer.

The costing is considered for two values as per specifications given by the manufacturer and actual values required for the specified range. In addition, the targeted values for 2020 and 2030 are also shown and used for calculation. It is observed that most of the cost is for the battery. There is an extreme need for reduction of this cost. The initial investment required for conversion with rating specified and costing given in Table 2 is summarized in Table 3 for PMM.

Table 3 Initial Investment for Conversion with PMM

Initial Cost (Investment)	Component Cost in ₹ (Standard)			Component Cost in ₹ (Actual)		
	2017	2020	2030	2017	2020	2030
Battery	1,78,816	1,67,640	1,43,256	3,18,208	2,98,320	2,54,928
PEC	5715	3810	3175	10,170	6780	5650
Charger	20,000	15,200	10,000	20,000	15,200	10,000
PM motor	14,654.4	11,360	11,360	16,285	12,624	12,624
Other including Labour*	10,000	12,000	15,000	10,000	12,000	15,000
Total cost	2,29,185	2,10,010	1,82,791	3,74,663	3,44,924	2,98,202

The initial investment with standard values for conversion at current international market rates is observed to be around 2, 29,185. It is expected to reduce to 2,10,010 by 2020 and around 1,82,791 by 2030. Initial investments for actual values of components considering the efficiency of battery 80% and 70% utilization of battery comes above 3,00,000 which is very high and expected to come down to 2,98,202 by 2030. Figure 9 shows the bar chart of initial investment for conversion with PMM motor.

Figure 9 Initial Investment for Conversion.

The running cost for CV and CPHEV running for a distance of 60 and 100 km/day in the city (for Sample Indian urban driving cycle) is shown in Table 4.

It can be seen that electricity costing is less than conventional one in both cases. The yearly running cost comparison of conventional vehicle and converted PHEV and its saving for driving about 60 km/day and 100 km/day with the standard and actual values can be seen in Figures 10(a) and 10(b) respectively.

Table 4 Running Cost

Distance Travelled		CV				CPHEV						
km/ day	km/ year	Diesel (₹/ litre)	Mileage# (km/litre)	Cost/ year (₹)	Cost/ year (₹)	Electricity Rate (₹/kWh)	Standard Charging* kWh	Actual Charging* kWh	Standard Cost/ day (₹)	Actual Cost/ day (₹)	Standard Cost/ year (₹)	Actual Cost/ year (₹)
60	21,900	57.6	11.36	5.0704	1,11,042	7.2	14.1111	25.1111	101.60	180.80	37,084	65,992
100	36,500	57.6	11.36	5.0704	1,85,070	7.2	14.1111	25.1111	101.60	180.80	99,987	1,11,112

* Efficiency of charger – 90% and utilization of state of charge (SOC) of battery – 70%.

Figure 10 (a) Yearly Running Cost Comparison and (b) Yearly Saving by Conversion.

The payback and Return on Investment (ROI) for current and futuristic timeline for different values of ratings and are shown in Table 5.

Table 5 Payback Calculation						
Timeline	2017	2020	2030	2017	2020	2030
	(Standard)			(Actual)		
	(years)	(years)	(years)	(years)	(years)	(years)
Payback	2.69	2.47	2.15	5.07	4.66	4.03
ROI	37.12	40.51	46.55	19.74	21.44	24.80

It is observed from Table 5 that more saving is obtained for standard values with a payback of 2.7 years and expected to reduce to 2.15 years by 2030. The payback is increased if the higher rating of motor, battery and PEC is used to get the same range specified (actual values). The value increases to more than 5 years and expected to drop to 4 years by 2030. Figure 11 shows the glimpse of the same.

The payback is less than three years for standard values and expected to improve from 2.69 to 2.15 for standard and between 5.78 to 4.6 years for actual values from 2017 to 2030 years for PMM. The ROI is high for standard values i.e. 37.61% recently and expected to improve. However, with

Figure 11 Payback.

actual values, the ROI is not very promising and is only 17.46% expected to increase to 21.93% over the years from 2017 to 2030 as seen from Figure 12.

Figure 12 ROI.

3.2 Local Consideration

The costing for components available at the local market (Asian) [32] are given in Table 6 and their comparison on payback and ROI with reference to international calculation are provided in Figures 13 and 14.

Table 6 Costing of Components (Asian Market)

Components	Capacity				2017	Unit
	Standard		Capacity			
	Condition		Actual			
Battery	12.7	kWh	22.6	kWh	8970	₹/kWh
PEC	15.875	kW	28.25	kW	180	₹/kWh
Charger	Standard				10,000	₹
PM Motor	14.2	kW	15.78	kW	1032	₹/kW
IM Motor	14.2	kW	15.78	kW	824	₹/kW
Other including Labour*	*1% per annum per month rise in charges				240	₹

Figure 13 Payback Comparison of Local and International Market Costing.

Note: IM – International Market, LAM – Local Asian Market.

Figure 14 ROI Comparison of Local and International Market Costing.

Note: IM – International Market, LAM – Local Asian Market.

It is observed that the payback reduces from 2.69 years to 1.61 years for local prices of the component with a standard rating for PMM with the standard rating. With actual values, the payback reduces from 5.08 to 3.51 years for PMM.

ROI is 62.21% instead of 37.12% of local costing for standard values. ROI reduced drastically for actual values, however, with local components the ROI increases to 28.47% from 17.31% for PMM as shown in Figure 14.

4 Conclusion

Energy storage (battery) of electric powertrain decided the costing of an electric powertrain. However, battery technology required is unavailable in developing countries like India. Hence, international costing trends are studied and used to perform a cost analysis for conversion of CV into PHEV. Cost analysis is done with standard values specified by the manufacturer to achieve a specific range of vehicle and with actual values to achieve specified range. It is observed that with current costing at international level payback for 70 bhp engine converted to PHEV with 60 km range comes to be less than three years for standard values, however it increases to more than five years with actual values. ROI is observed to be around 37% and expected to increase to near

41% in 2020 and around 47% by 2030 for standard values. Moreover, with the local Asian market due to the comparatively lesser price of the battery, results are promising for conversion and payback is observed to be around 1.6 years for standard values and 2.7 years for actual values.

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