

# Vehicle Configurations for Sports Utility Vehicles and Small Cars

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**Abstract**— Worldwide transportation sector has witnessed dynamic developments in recent years. The motivation to reduce the dependence on fossil fuels and to reduce the environmental impact caused due to this sector paved way for the evolution of electric and hybrid electric vehicles. Today the world is looking at more advanced options like the plug-in electric or plug-in hybrid electric vehicles. In this scenario, the economic aspects of these vehicles assume great importance, especially for the developing countries. This paper considers an internal combustion engine-driven Sports Utility Vehicle (SUV) and a small car as the reference vehicles and derives equivalent electric and hybrid electric vehicle configurations for these. Further analysis indicates most economic configurations for the SUV and small car segments.

**Index Terms**— Hybrid electric vehicle, Transportation electrification, Fuel economy, Capital cost, Running cost, Sports Utility Vehicle, Performance analysis.

## 1 INTRODUCTION

THE use of electric power to drive vehicles has exposed a variety of research issues. Continuous efforts to solve these issues have resulted in considerable developments in the transportations sector. However, for any technology to be used widely, it has to be mature enough. This paper deals in land mode of transportation.

Since years, the land mode of transportation relied solely on the mechanical power delivered by the internal combustion (IC) engines. Today, advanced versions of gasoline and diesel engines have further strengthened the market for the internal combustion engine driven vehicles. Ever-depleting petroleum resources, huge environmental pollution caused by the transportation sector and low overall energy efficiency of IC engine driven vehicles encouraged the research on greater use of electricity in all forms of transportation.

The concept of transportation electrification [1] paved way for the emergence of Electric Vehicles (EV), which relied only on electric power for traction. However, the issues related to the energy storage system [2] were the greatest limitation of these vehicles [3]. Electric battery modules and fuel cells are the only feasible options, which can be directly used in these vehicles. As these technologies are not mature enough, they are expensive. Moreover, the range provided by the battery between two consecutive charges is much less compared to a full tank gasoline or diesel driven vehicle. This led to the evolution of Hybrid Electric Vehicles (HEV). HEV could benefit from the huge range provided by gasoline or diesel, while help in improving the overall system efficiency by making judicious use of electricity for traction.

There are various factors, which lead to the choice of vehicle configuration [4]. Some of the key factors which influence this

choice are: size and curb weight of the vehicle, passenger or cargo carrying capacity of the vehicle, maximum speed and acceleration desired from the vehicle, maximum gradeability, type of driving cycle intended for the vehicle (urban or highway type) and so on. However, in spite of all the above considerations, the option, which is economic, might prove to be most popular, especially when the intended vehicle is to be launched in a developing country like India.

The factors that are responsible for huge cost of these vehicles are number of extra components and their sizes, size of the battery module and other additional features that provides high standards of safety, comfort and performance to the users [5].

This paper reviews some of the electrified forms of passenger vehicles and gives an idea about the additional components in each of them. An SUV [6] and a small car that are currently available in Indian markets were taken as the reference. Equivalent electric and hybrid electric vehicles corresponding to these reference vehicles were derived. Based on the component sizes of each of them and their fuel economy, their capital and running costs were estimated. These results were then used to highlight the relevant observations and arrive at valuable conclusion.

The remaining parts of this paper are arranged as follows: Section 2 reviews different architectures of electrified vehicles. Section 3 explains the methodology adopted to derive the vehicles equivalent to a particular SUV and a small car. This section also explains the methodology adopted for analyzing the performance and cost of all the vehicles. Section 4 presents all the results of the analysis and discusses them in detail. Finally, section 5 presents the conclusion.

## 2 ELECTRIFICATION OF LAND TRANSPORTATION: VARIOUS CONFIGURATIONS

Large-scale research in the area of transportation electrification and ever-growing interest of people in this area has already resulted in many versions of HEVs landing in the market. More and more developments in this sector shall result in expansion of HEV market all over the world. The current sec-

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tion deals with the major components in the four basic configurations of land vehicles, namely, the electric vehicle, the series hybrid, parallel hybrid with independent starter and alternator and parallel hybrid with starter-alternator configurations. Other advanced and more complex forms of hybrid electric vehicles, which evolved later, were not considered in this analysis.

### 2.1 Electric Vehicles

These are vehicles, which are driven using electric power alone [7]. Internal combustion engine is the least efficient component in any conventional vehicle. Electric vehicles do not employ any IC engine and hence are highly energy efficient vehicles. An electric motor and the energy storage module that delivers the electric power for the proper operation of the motor are the major components that are included in the powertrain. Electric battery modules or fuel cells are the two options currently available for HEV manufacturers. Among the various options for electric battery, Nickel Metal Hydride (NiMH) and Lithium Ion Battery are currently the most popular options. Other variants of lithium-based batteries that seem to be promising candidates are not sufficiently mature technologies. Permanent magnet synchronous motors (PMSM), because of their high efficiency of operation, are the best choice of motor for any electrified vehicle. However, for large vehicles, the huge size of permanent magnets in the motor results in high overall price of the motor. Hence, induction motors are widely preferred for these applications, based on the cost/performance ratio. There are other motor candidates like switched reluctance motor, which seem to be promising candidates.

The limiting factor in this class of vehicles is the huge cost of battery modules. Both lithium ion battery and NiMH battery modules are quite expensive and prove to be critical as the size of the vehicle increases.

### 2.2 Series Hybrid

The architecture of Series hybrid is well presented in [7].

The electric motor has to be sufficiently rated so as to handle the peak traction power demanded by the vehicle. This automatically requires the electric battery modules also to be of sufficient size. The biggest advantage of this class of vehicles is that the IC engine is never used for directly providing the traction power to the vehicle wheels. It is operated to run a generator machine, which is used either to charge the battery modules or is bypassed from the battery to the electric traction motor which propels the wheels.

In this configuration, the engine is decoupled from the road load, so that the engine will not undergo any abrupt changes in operating conditions, will have little idling time and shall cause reduced emissions. Due to longer powertrain compared to parallel hybrids, these vehicles have lower overall system efficiency.

### 2.3 Parallel Hybrid

Two kinds of parallel hybrids are considered for the current study: one with the starter-alternator configuration and another with independent starter and alternator. Electric power-

assist strategy is popularly used in these vehicles. IC engine is the primary source of traction power for the vehicle, while the motor only assists the engine when needed. The differences in the architecture of both these configurations can be understood from [7].

Parallel hybrids can again be classified into three, based on the hybridization factor [8]: Micro, mild and full hybrids. This classification is based on the relative sizes of the components in the electric and the mechanical powertrains. Only mild hybrids are considered in this study, to minimize the component sizes in the electric powertrain and hence to minimize the prices.

## 3 ANALYSIS OF EQUIVALENT VEHICLES: DATA AND METHODOLOGY

The two classes of passenger vehicles identified for the analysis were the SUV and small car. The reason for these choices was their popularity among wide range of the population. The first step in the current analysis was to identify suitable IC engine driven SUV and small car as the reference vehicles.

Tata Safari Petrol Exi and Maruti Suzuki Ritz (Petrol) are the SUV and small car considered as the reference vehicles for the analysis. The specifications of these vehicles are presented in table I. The following conditions were ensured for the entire analysis:

- 1) Same battery, motor, generator and fuel converter type.
- 2) Same grade and acceleration constraints.
- 3) Same cargo + passenger load.
- 4) Maximum Degree of Hybridization = 1, which implies optimization of component sizes shall result in a vehicle with smallest possible fuel converter/ engine.  
 (Higher degree of hybridization improves the fuel economy and vehicle performance until a critical optimum point is

TABLE I  
 SPECIFICATIONS OF TATA SAFARI PETROL EXI (4X2 DRIVE) AND MARUTI SUZUKI RITZ (PETROL)

S/ N	Parameter	Tata Safari Petrol Exi (4x2Drive) [9- 10]	Maruti Suzuki Ritz (Petrol) [11-12]
1.	Curb weight (kg)	1935	1005
2.	Gross weight (kg)	2550	1430
3.	Cargo capacity (kg)	615	425
4.	Average fuel economy in Indian cities (L/100km)	15.38	5.83
5.	Maximum speed (km/h)	140	175
6.	Time taken to accelerate from 0 to 100 km/h (s)	16.8	13.3
7.	Maximum grade ability (%)	40	-

reached, beyond that, the vehicle performance may be affected

adversely [22]. Thus, the actual degree of hybridization shall be fixed at this optimum point)

- 5) Battery type considered was Lithium ion battery.
- 6) Spark ignition or Petrol/Gasoline engine was considered for the current study.
- 7) Fuel Economy (city) = 16L/100 km or better (for SUV), 7L/100km or better (for small car). These values are based on the fuel economy values of two cars found on Indian roads, namely the Tata Safari Petrol Exi (SUV) and Ritz (small car).

The performance constraints formulated to derive other vehicle configurations equivalent to Tata Safari are presented as follows:

A. Acceleration Constraints

- 1) Maximum speed desired: 152km/h

- 2) .

- 3) .

- 4) S/

- 5) N

- 6) .

- 7) 1. ICE

- 8) 2. Electric Vehicle

- B. 3. Parallel Hybrid (Independent starter and alternator)

- 1) .

- 2) .

- 3) .

4. Series Hybrid

5. Parallel-

- C. Starter Alternator

- 1) .

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C. Mass Constraint

- 1) Mass of the Cargo: 136 kg.

The remaining steps of analysis have been listed as follows:

- 1) The equivalent electric and hybrid electric configurations corresponding to the Tata Safari and Maruti Suzuki Ritz were derived and the sizes of major components in them were noted.
- 2) The City-Highway test procedure [21] as incorporated in ADVISOR was run and the city, highway and combined fuel economy of all the vehicles, obtained through step 1), were noted. This test procedure involves a cold start FTP-75 cycle or UDDS cycle (city driving cycle) and a hot-start HWFET cycle (highway driving cycle). The combined fuel economy is calculated using (1):

$$FE_{cmb} = [(0.55 \times FE_{CTY}) + (0.45 \times FE_{HWY})] \times 235.27 \quad (1)$$

where,

FE\_cmb = Combined fuel economy.

TABLE III

VEHICLES WITH COMPONENT SIZES OPTIMIZED FOR A PERFORMANCE EQUIVALENT TO MARUTI SUZUKI RITZ (PETROL)

S/N	Vehicle Type	Vehicle Mass (kg)	Fuel Converter (kW)	Motor (kW)	Generator (kW)	No. of Li-Ion Battery modules	Max Grade @54.7 km/h	Max Acceleration (m/s <sup>2</sup> )	Max Speed (km/h)
1.	ICE	984	41				18.7%	2.8	155.8
2.	Electric Vehicle	841		50		34	33.4%	5	152.7
3.	Parallel Hybrid (Independent starter and alternator)	989	22	15		18	13.3%	5	152
4.	Series Hybrid	1038	26	25	30	15	13.3%	4.3	117.8
5.	Parallel-Starter Alternator	989	22	15		18	18.5%	4.4	152.3

IC engines in each hybrid.

Similarly, the following constraints were formulated to derive other vehicle configurations equivalent to Maruti Suzuki Ritz:

A. Acceleration Constraints

- 1) Maximum speed desired: 152 km/h
- 2) Time taken to accelerate from 0 to 100 km/h < 150 s.
- 3) Time taken to accelerate from 64.4 to 100 km/h < 100 s.
- 4) Time taken to accelerate from 0 to 152 km/h < 300 s.
- 5) Distance travelled in 5 sec > 0.3048 m
- 6) Time taken to travel 0.402 km/h < 200 s.
- 7) Maximum acceleration > 0.3048 m/s<sup>2</sup>
- 8) Maximum Speed > 90 km/h

B. Grade Constraints

- 1) Max grade which the vehicle can climb < 10%
- 2) Speed at which the vehicle can climb the grade = 54.7 km/h.
- 3) Duration for which the vehicle has to maintain 54.7 km/h on the maximum grade = 10 sec

4 RESULTS AND DISCUSSIONS

Based on the component size optimization procedures [7] for various vehicle architectures and the two sets of performance constraints as discussed in Section 3; Table II and Table III give the component sizes, maximum speed, maximum acceleration and maximum grade ability of various types of vehicles corresponding to Tata Safari and Maruti Suzuki Ritz respectively. China and India are the countries with highest population in the world. In these countries, larger vehicles like Sports Utility Vehicles (SUVs) may be used by a big family, a group of employees of the same firm or such groups of persons with identical daily travel needs. These vehicles are expected to reduce the environmental pollution and decrease the electric power or fuel consumption per person, compared to a large number of smaller cars catering the needs of separate individuals. However, when the total cost of the vehicle becomes the major deciding factor, small car shall definitely have an upper hand over a SUV. This scenario is most likely to arise for a small family with medium income. Such families constitute a signif-

TABLE II  
VEHICLES WITH COMPONENT SIZES OPTIMIZED FOR PERFORMANCES EQUIVALENT TO A TATA SAFARI PETROL EXI (4X2 DRIVE)

S/N	Vehicle Type	Vehicle Mass (kg)	Fuel Converter (kW)	Motor (kW)	Generator (kW)	No. of Li-Ion Battery modules	Max Grade @54.7 km/h	Max Acceleration (m/s <sup>2</sup> )	Max Speed (km/h)
1.	ICE	2781	132				28.24%	2.7	179.68
2.	Electric Vehicle	2794		500		235	26.5% @10 for 400s	4.69	155.82
3.	Parallel Hybrid (Independent starter and alternator)	2791	124	35		13	25.97%	4.58	180.13
4.	Series Hybrid	3127	150	150	172	75	16.4% @ 6.5 mph for 60 secs	4.69	157.46
5.	Parallel- Starter Alternator	2760	129	75		12	25.7%	2.65	61.64

ificant percentage of the total population and hence the small car segment of passenger cars shall also enjoy good market share.

The following observations are of relevance in this study:

- 1) For tough cargo, speed/ acceleration and grade constraints, a parallel hybrid with starter alternator configuration gives the lightest vehicle. However, a parallel hybrid with independent starter and alternator gives a reasonably light vehicle with high acceleration and grade performance. Such a vehicle is expected to provide the highest maximum speed. The difference in the performance of the two vehicle types is not so significant in small cars.
- 2) For relaxed cargo, speed/ acceleration and grade constraints, an EV gives the lightest vehicle after optimization of component sizes. However, a parallel hybrid with starter-alternator configuration gives a reasonably light vehicle with high acceleration, maximum speed and grade performance.
- 3) For both tough and relaxed constraints, the series hybrid

Further analyses on the performances of these vehicles were conducted, to determine the total cost involved in owning these vehicles. The fuel economies of these vehicles obtained through City-Highway test procedure are presented in table IV.

The following observations shall be made from the results of the City-Highway test:

- 1) For any vehicle configuration, the small car is found to have better fuel economy figures than the equivalent SUV.
- 2) Besides electric vehicle, the parallel hybrids with independent starter and alternator possess the best fuel economy figures.
- 3) Among the various vehicle configurations for the SUV, the parallel hybrid with starter-alternator configuration has the worst fuel economy figures.
- 4) Among the various vehicle configurations for the small car, the series hybrid has the worst highway fuel economy and combined fuel economy, while the parallel hybrid with the starter-alternator configuration has the worst city fuel

TABLE IV  
FUEL ECONOMIES OF VEHICLES BASED ON THE RESULTS OF CITY-HIGHWAY TEST

S/N	Vehicle type	City	Highway	Combined
1.	Parallel hybrid SUV (independent starter and alternator)	11.8	9.3	10.7
2.	Parallel hybrid small car (independent starter and alternator)	4.7	3.9	4.4
3.	Parallel Starter Alternator - SUV	26.1	52.6	38
4.	Parallel Starter Alternator - Small car	5.7	3.9	4.9
5.	Series hybrid - SUV	14.4	13.6	14
6.	Series hybrid - Small car	5.2	4.7	5
7.	Electric Vehicle - SUV	6.1	5.2	5.6
8.	Electric Vehicle - Small car	1.7	1.6	1.6

vehicle provides the heaviest option.

- 4) Irrespective of the degree of toughness of the constraints, an EV is expected to have highest number of battery modules compared to all other electrified vehicles of similar class. Greater the toughness of the constraints, greater shall be the percentage difference in the optimal number of battery modules with respect to the lightest vehicle.

economy.

The total costs of the major components in each of the different vehicle configurations considered in the current study were calculated using the data listed in section 3. Using the same set of data, the running cost for each vehicle is also calculated. All the results of this cost analysis is presented in table V.



The following are the observations from the cost analysis:

- 1) The parallel hybrid with independent starter and alternator configuration has the lowest capital cost, running cost and total cost in the SUV category, while the series hybrid configuration is seen to have the lowest associated costs among the small car category.
- 2) For the same set of performance constraints, the electric vehicle is found to be most expensive configuration for both SUV and small car category.
- 3) Increasing the depth of discharge of the battery and re-charging it to high state of charge shall affect the battery life as well as the running cost of the vehicle.
- 4) The monetary benefit of Parallel hybrid with independent starter and alternator configuration over the starter alternator configuration is quite large for the SUV category, while it is far less for the small car category.

## 5 CONCLUSION

The SUV and the small car segments together contribute a major percentage of the profits from the entire passenger car market. The performance analysis and the cost analysis of the major components in each of these vehicles help in selection of the right vehicle type and configurations. This paper helps in selection of the right vehicle type and configuration based on the vehicle weight, performance, type of driving cycle (city or highway), cost of major components and the running costs involved with each of these vehicles.

TABLE V  
COSTS ASSOCIATED WITH VARIOUS VEHICLE ONFIGURATIONS OF SUV AND SMALL CAR

S / N	Vehicle	Cost of major components (\$)		Running Cost (\$)		Total Cost (\$)	
		SUV	Small Car	SUV	Small Car	SUV	Small Car
1.	Electric Vehicle	50,144	7,034	85,10,346.75	12,71,649.75	85,60,490.75	12,78,683.75
2.	Series Vehicle	22,120	4,210	14,60,322	3,95,402.25	14,82,442	3,99,612.25
3.	Parallel hybrid with Independent Starter and Alternator	6,590	4,266	6,45,620.25	3,95,974.5	6,52,210.25	4,00,240.5
4.	Parallel hybrid with starter-alternator	6,924	4,266	19,94,888.25	4,20,642	20,01,812.25	4,24,908

tracting considerable research activities in this area. However, this study sheds light on the importance of favourable government policies in order to cut down the costs associated with the ownership of these vehicles.

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The benefits of transportation electrification are indeed at-