“Measurement and Analysis of Indian Road Drive Cycles for Efficient and Economic Design of HEV Component”

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Abstract

Drive cycle pattern is different for different countries which depends on their traffic density, road condition and driver discipline. Drive cycle influences HEV’s components design, sizing and their ratings. Standard drive cycle data doesn’t reveal much information to determine efficient and economic design of HEV’s components. In this research paper measurement and analysis of real time Indian road drive cycles (IRDC) are carried out for urban roads, state highway, national highway and express Highway where vehicles have their most run. Real time drive cycle data will expose impact of driver’s skills, traffic, road conditions and short acceleration / deceleration period, which can be represented on drive cycle chart. Analysis of IRDC in terms of rate of acceleration and deceleration, top speed, average speed with road length and analysed mathematically to find energy and power required for acceleration, normal operation and energy harvested during deceleration. Based on information from IRDC HEV’s components initial size are estimated. Initial estimated size is optimized to make HEV’s components design more efficient and economic. Teaching and learning based optimization algorithm (TLBO) and Multi objective genetic algorithm (MOGA) are used to optimize HEV’s components. Constraint of optimization algorithm are like engine and motor rating should be selected such that it has effective top speed with enough acceleration capability and can run enough distance to reach destination according to Indian urban, state, national and express highway pattern where cities are very closed compared with other countries and its regeneration component design should able to harvest maximum deceleration energy. For economic operation of HEV’s, running cost in terms of Rs. / Km. should be minimum.

Keywords: Indian Road Drive Cycle, Hybrid Electric Vehicle Component, Efficient and Economic, Analysis of Drive Cycle, Drive Cycle and HEV

NOMENCLATURE

| Symbol | Description                  |
|--------|------------------------------|
| V_{OC} | Battery open circuit voltage (V) |
| E₀     | Battery constant voltage (V)  |
| R      | Internal resistance (Ohm)    |
| i      | Battery current (Amp)        |
| K      | Polarization constant (V/Ah) |
| Q_{it} | Actual battery charge (Ah)   |
| Q_{at} | Total charge of battery (Ah) |

Exp (t) = \text{Exponential zone voltage (V)}
\frac{dw}{dt_{(<0)}} = \text{Change in watt (W)}
V_{charge} = \text{Charging voltage (V)}
V_{total} = \text{Total voltage (V)}
C_{cc} = \text{Charge constant}
1 Introduction

India is growing market for automobile where biggest class of consumer is middle class family. Many automobile companies have already started research in HEV which has ability to use non-conventional energy which is bestowed amply in India. HEV also become has economic choice for Indian consumer and for Indian environment. Government of India is also planning to give subsidy for HEV to motivate consumers to buy HEV. Fuel energy costs more than electric energy according to electric tariff plan. [1]

Design of HEV’s components is began with studying drive cycle. Drive cycle pattern depends on road condition, road type, traffic density and driver’s behaviour [5].

There are different standard drive cycle available from different countries e.g. ECE-15, EUDC, EPA Federal Test [28]. These drive cycle data
are used for vehicle emission analysis and for estimation of HEV’s components size. Standard drive cycles do not reveal information like rate of acceleration & deceleration and its power, peak power demand & actual time of travelling [2]. Efficient and economic design of HEV’s components cannot be done based on information and analysis from standard drive cycle. Design of motor, IC engine, battery is depended on load pattern. Different countries have different drive cycle pattern, so for actual information India road drive cycle must be measured in real travel time. Real time data of drive cycle are necessary to be measured and to reveal detailed information about drive cycle load pattern. Real time drive cycle measurement goes through natural environmental condition of all different type of roads, different type of road condition and different type of traffic condition which gives different drive cycle for different roads so it can be used for HEV’s components size estimation [3].

For the selection of power train configuration different power train configurations are available. All power train serves different purpose. There are different types of configuration of power train which are series design, parallel design, and series & parallel design. Dynamic model of vehicle is used for modelling and simulation and it is used to calculate vehicle power requirement which is close to actual performance [6, 7].

Variety of drive cycle pattern has to be considered while HEV’s components initial sizing is determined. For initial sizing rule based theorem, different estimation method [27] and mean value models [29] are used. The optimum component size should be calculated by proper optimization method because direct initial sizing will not give a solution that works efficiently with different drive cycle patterns [8].

To select optimum component size optimization should be done. Certain constrain are set while optimization process is taking place. Different optimization techniques can be used like swarm optimization, genetic algorithm optimization, multi objective genetic algorithm optimization and teaching and learning based optimization. TLBO method is never used for HEV’s components optimization.

Estimated component size can be optimized by GA. It uses derivative and it achieves single objective. It selects random values from population which is data derived from drive cycle. Fittest value is found from population. Limitation of this method is it doesn’t perform multi objective tasks [9]. Multi objective genetic algorithm is evolved method or modified method from GA. This method is able to satisfy multi objective laid down in single set of iteration flow. Iteration stops when fittest values are achieved, which is considered fittest among population and is solution [10, 11]. Swarm optimization can be used to solve complex solution. It dose investigation of population by considering multi objectives as well as limitation set to those objectives. Control strategy for can also be optimized by swarm optimization technique [12, 13]. Teaching and learning based optimization method is recent development in field of optimization technique which is also inspired by nature of classroom working environment where teacher teach learners behave during study. For HEV’s components optimization this method can be useful because normally population size is high and multi objective supposed to be achieved while designing HEV’s components. In TLBO method learners which are drive cycle population learns to become best by comparing their data with each other and also modify them to achieve multiple objective and set control strategy.

After optimization of component size their performance parameters are checked and their running economy is also compared with conventional IC engine car which are present in India [14, 15]. Throughout the paper parallel configuration of HEV is considered which is explained in section 2. Information about real time drive cycle a method measurement on different Indian roads and its analysis cycle is done in section 3. Modelling of HEV’s components is done in section 4. In section 5, initial estimation of components is done by considering parameters of drive cycle. In section 6 initial estimation value is optimized by TLBO method which is new and never used for HEV’s component size optimization and MOGA method to make comparison. Economical comparison is shown in section 7. Result of all method of optimization is shown in section 8 and it is concluded in section 9.

### 2 System Configurations

HEV’s components design is done for medium size vehicle. Various drive train configurations can be used for HEV. Selection of drive train pattern depends upon application. In this paper parallel drive train configuration is used. Parallel
drive train requires less space compared to series configuration and is suitable for use in medium sized car. Series configuration is used for heavy duty application and its drive train requires additional generator space.

Figure 1 Shows block diagram of Parallel drive train configuration. For parallel drive train configuration battery, fuel tank, IC engine, motor and inverter, splitter which splits load between IC engine and electric motor and this entire set of components are connected to the a load.

Figure 1: Parallel HEV

Here rating of IC engine and electric motor are 50% of load. Rating of IC engine can be chosen higher than 50% of load depending upon its maximum efficient point. Dynamic model of HEV is used for modelling and analysis of vehicle parameters. Figure 2 Shows block diagram of dynamic model of HEV. As drive train component Lead-Ion battery, BLDC motor, diesel CRDi IC engine is selected.

Figure 2: Dynamic Model of HEV

3 Indian road drive cycle

3.1 Drive cycle measurement

The driving cycle is sequence of vehicle operating condition i.e. idling, acceleration, cruise, creeping and declaration with respect to time for a given city, region or a country. Indian roads are categorized in four ways which are (i) express highway (ii) national highway (iii) state highway (iv) urban roads/rural road [4]. So, the selection of population and road is very crucial while planning drive cycle measurement program. All type of Roads should be covered. Vehicle selection is also very crucial. Vehicle of similar rating should be selected as rating of HEV to be designed. Vehicle which is most economic while running is selected to start drive cycle measurement program. Table 1 shows parameters of vehicle to determine drive cycles.

Table 1: Vehicle Parameters

| Vehicle HP | 128HP |
|-----------|-------|
| Vehicle RPM | 6000 |
| Tractive Effort coefficient for Indian roads | 0.4 to 0.5 |
| Mass of Vehicle | 1300 Kg |
| Rolling resistance coefficient in this case | 0.013 (asphalt road) |
| Height of CG from ground | 87 cm |
| Effective radius of tire | 29 cm |
| Distance between wheels | 268.5mm |

For the purpose of measurement of drive cycle medium sized car with diesel engine is used. Medium size cars are economical choice in India. Drive cycle measurement is carried out by android application which uses global positioning system by traveling in car. Data of time to speed were measured and plotted in android application and those were loaded in Microsoft excel. To collect legit drive cycle data the vehicle is driven in to natural environment.

3.2 Characteristic of IRDC

For different type of road the drive cycle parameters varies considerably as it can be observed from figure 3. It can be observed that for express highway max speed and max HP is
high but time of run is Less and from urban roads observed that acceleration and deceleration cycle is very high compared with Express highway but max HP and max speed is low while national and state highway both requires high run time form HEV [16, 17].

3.3 Analysis
Table 2 shows data of which are derived from real time drive cycle termed as drive cycle of different road (DC), average speed (AS), maximum speed (MS), Average Time (AT), Maximum Time (MT), total time(T) and distance (D). Data are categorized by means of road types E, N, S, C and U stands for express highway, national highway, state highway, state and national highway and urban road respectively.

It can be said that all drive cycle will have different requirements from power train. Express highways requires higher average HP and maximum HP while national and state highways requires vehicle to run for long time so design of HEV’s components should fulfill both load drive cycle characteristic.

Table 3 shows summary values of data from table 2 which enables to understand marginal difference in characteristics of different road drive cycle measured in real time.

3.4 Vehicle Dynamics
Vehicle dynamics are considered for calculation performance parameter of HEV. Vehicle’s calculates performance parameter like its horsepower requirement, speed, torque, and acceleration & deceleration power can be determined by vehicle dynamics.

Table 2: Mean Values of Drive Cycle Parameters

| DC             | AS  | MS  | AT  | MT  | T  | D  |
|----------------|-----|-----|-----|-----|----|----|
| Express Highway|     |     |     |     |    |    |
| E              | 106 | 147 | 103 | 143 | 45 | 80 |
| National Highway|    |    |    |     |    |    |
| N1             | 57  | 97  | 57  | 95  | 23 | 22 |
| N2             | 83  | 38  | 81  | 135 | 209| 220|
| N3             | 63  | 135 | 62  | 122 | 95 | 100|
| N4             | 81  | 133 | 79  | 130 | 25 | 33 |
| N5             | 70  | 105 | 68  | 102 | 140| 170|
| State Highway  |     |     |     |     |    |    |
| S1             | 66  | 115 | 64  | 112 | 51 | 60 |
| S2             | 60  | 115 | 58  | 112 | 171| 171|
| S3             | 61  | 119 | 60  | 116 | 27 | 27 |
| S4             | 79  | 141 | 77  | 138 | 50 | 65 |
| State & National Highway | | | | | |
| C1             | 78  | 131 | 76  | 128 | 76 | 98 |
| C2             | 76  | 126 | 74  | 123 | 186| 235|
| Urban Road     |     |     |     |     |    |    |
| U1             | 26  | 63  | 28  | 60  | 23 | 9  |
| U2             | 32  | 79  | 32  | 77  | 17 | 9  |
| Avg            | 70  | 114 | 68  | 118 | 85 | 99 |

Table 3: Drive cycle summary

| DC             | AS  | MS  | AT  | MT  | T  | D  |
|----------------|-----|-----|-----|-----|----|----|
| Express Highway|     |     |     |     |    |    |
| E              | 106 | 147 | 103 | 143 | 45 | 80 |
| National Highway|    |    |    |     |    |    |
| N              | 63  | 101 | 62  | 98  | 81 | 96 |
| S              | 71  | 120 | 69  | 117 | 118| 147|
| U              | 29  | 71  | 30  | 68  | 20 | 9  |

\[ F_{t\text{ total}} = F_{t\text{ max}} + F_r + F_w + F_g \] 
\[ \ldots (1) \]

\( F_{t\text{ total}} \) is total force required at front axle which considers resistance forces of road and car to calculate actual force required by car. From force torque, speed and horse power are calculated which are shown in table 2 and 3.
For simulation and modelling of parallel configuration of HEV, modelling equations are mentioned below.

1. Battery charging, discharging model [21]

- Discharge Voltage Status

\[ V_{OC} = E_o - R \times i - K \frac{Q}{Q_{ic}} (i + i) + \exp(t) \]  

- Charging Voltage Status

\[ V_{charge} = \int \left( \frac{\alpha}{\alpha} \times \frac{w}{w} \times V_{total} \times C_{cc} \right) dt \]  

- SOC Calculation [22]

\[ Q_{ut} = V \times I \times (T) = VlH \]
\[ Q_{ut} = WH \]
\[ Q_u = WH - \int_0^T (t) dt \]  
\[ K = \frac{Q_{ut}}{Q_{ult}} \times 100\% \]

2. Brushless DC motor model [23]

Modelling equations of brushless DC motor

\[ I_s = \frac{P}{2 \pi \times W_{sync}} \]  
\[ T = \frac{T}{L_{st}} \]
\[ L_{st} = 2 N \times N \times B \times R \times L \]  
\[ T = \int_{t}^{t} \frac{\omega_m}{dt} + T_L + B \omega_m \]
\[ \omega_m = \int_{t}^{t} \frac{T-T_L}{I} \]  
\[ T_m = \frac{P}{\omega_m} \]

3. Throttling model [24]

Throttle model is done by making look up table from standard throttle opening to fuel output graph of IC engine.

4. IC engine model [25]

\[ B_{HP} = \frac{P \times A \times L \times N \times N}{60} \]

\[ P_i = \text{Indicated mean effective pressure} \]
\[ A = \text{Bore area} = 0.05 \]
\[ L = \text{Length of displacement} = 0.065 \]
5. Fuel tank model
By calorific value model
Total energy in car,
Diesel calorific value $D_{cal} = 46000$
Tank capacity $T_c = 22.5$
Time (sec) $T = 3600$
$D_{cal} \times T_c \times T = 3.726 \times 10^9$ Calorie

From this simulation model parameters like SOC%, fuel consumption, battery consumption, torque & horsepower production will be analysed.

5 Influence of drive cycle in HEV's components sizing
The main component of HEV’s power train are battery storage, power rating of electric machine and size and rating of IC engine and it’s fuel tank capacity [20]. All this components mainly determines initial cost of HEV’s power train. Running cost is determined by fuel/battery power consumption.

To determine components size of HEV first step is to collect data of real time drive cycles of roads where HEV is to be driven.

Influence parameter for battery ampere-hour rating is determined by how long vehicle has to be travelled which average distance of different is charging station and acceleration power requirement of motor.

Similarly size of IC engine and motor is determined by average power and peak power required to fulfil drive cycle load requirement [19].

Deceleration energy determines rating recharging circuit which should be capable of holding and harvesting deceleration power. Deceleration and acceleration power is higher in urban roads and state highway while it is considerably less in express highway.

From figure 5 and 6 initial component size can be estimated. Initial estimation is done to begin designing process of HEV’s component.

Initial estimation of components is derived without keeping any constraint by simply finding means of drive cycle parameters. Initial sizing is done by mean value method and results are;
Motor rating = 60hp
IC engine rating = 60hp
Battery rating = 22.7kw
Fuel Tank = 22lit.

Initial sizing is not done by any algorithm or any designing method but simply by considering the influence of drive cycle on HEV’s component sizing and from table 3 which shows mean load demand [27].

From this initial sized data of component, optimization will be done with consideration of constraints.
Table 5: Rating from result of optimization

| Optimization Method/Final Rating | Motor (HP) | IC Engine (HP) | Battery Rating (kw) |
|---------------------------------|------------|----------------|---------------------|
| Mean Value                      | 60         | 60             | 22.7                |
| TLBO                            | 45         | 45             | 21.5                |
| MOGA                            | 50         | 50             | 21.5                |

7 Economy

Economy of running HEV is based on electricity and fuel prices on year 2015. It is calculated in terms of Rs/km. Rs/km for conventional IC engine and HEV which contains design component are calculated [27]. How much money needed to be spent for kilometre ride for any drive cycle is compared in result.

Table 6: Running cost

| Car Type | Rs/KM | Road          |
|----------|-------|---------------|
| IC Engine| 3.005 | Express highway|
| HEV      | 1.45  | Express highway|

HEV have lower running cost as compared to conventional IC engine type car which could be prime factor to motivate Indian consumer to buy HEV technology based car.

8 Results

Table 7, 8, 9 shows result of different optimization method. Component sized from mean value method shows it to be least efficient among three.

Optimization by TLBO shows 4% in rpm drop which means 4% less acceleration than mean value method of component design while it shows efficient IC engine operation which is less efficient component in any HEV.

By results of TLBO optimization method with MOGA optimization method it shows result came from TLBO are efficient than MOGA but it shows drop of rpm of 1.5% compared with MOGA.

TLBO method reduces component size to 25% and with MOGA method to 20% compared with results from mean value method.

These optimized component size were put in to different drive cycle condition where none of the result shows any variation in its performance and TLBO is able to sustain all drive cycle characteristics by dropping 4% in RPM even with 25% less in HP rating.

Table 7: For state highway

| Designing Method | HP | Battery SOC % | Fuel Left % | RPM Drop % |
|------------------|----|---------------|-------------|------------|
| Mean Value       | 120| 76.08         | 40.12       | 0          |
| MOGA Optimization| 98 | 77.26         | 44.66       | 2.5        |
| TLBO Optimization| 90 | 78.7          | 51.12       | 4          |

Table 8: For urban highway

| Designing Method | HP | Battery SOC % | Fuel Left % | RPM Drop % |
|------------------|----|---------------|-------------|------------|
| Mean Value       | 120| 98.06         | 99.47       | 0          |
| MOGA Optimization| 98 | 98.19         | 99.51       | 2.5        |
| TLBO Optimization| 90 | 98.25         | 99.57       | 4          |

Table 9: For express highway

| Designing Method | HP | Battery SOC % | Fuel Left % | RPM Drop % |
|------------------|----|---------------|-------------|------------|
| Mean Value       | 120| 92.64         | 40.12       | 0          |
| MOGA Optimization| 98 | 92.9          | 90.33       | 2.5        |
| TLBO Optimization| 90 | 92.81         | 51.12       | 4          |

9 Conclusion

Drive cycle is measured for Indian road that revealed its numerous characteristics. There is major variation in drive cycle for different road type. From cycle data component size were estimated and optimized with new method which
is TLBO. To observe TLBO method’s effectiveness it was compared with MOGA method of optimization. Results were simulated in MATLAB on with dynamic model of vehicle and modelling of parallel HEV’s components. Component selected by different optimization methods were put through different drive cycle and it did show that optimization done by TLBO method selects component size that is less than other two component size result derived with different methods. TLBO component rating is less than other two but still it is able to sustain different drive cycle load characteristics by only 4% drop in RPM. TLBO method proves to be optimizing HEV component more effectively because it has capability to modify data that suits different criteria. By optimal reduction in HEV component size with TLBO method the running cost of vehicle is reduced up to 50% by reducing rating of component. TLBO method is very effective tool of optimization of HEV for versatile drive cycle characteristics as Indian road have.

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