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

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\end{footnotesize}

Abstract

Drive cycle pattern is different for different countries which depend on their traffic density, road condition and driver discipline. Drive cycle influences HEV’s component’s 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 real time drive cycles pattern are measured and analysed in different category which includes 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. Measurement and analysis of real time Indian road drive cycle (IRDC) was carried out. Analysis of IRDC in terms of rate of acceleration and deceleration cycle, top speed, average speed with road length and analysed mathematically to find energy and power required for acceleration and normal operation as well as energy harvested during deceleration. Based on information from IRDC HEV’s component’s initial size were estimated. Initial estimated size is optimized to make HEV’s component design more efficient and economic. Teaching and learning based optimization algorithm (TLBO) and Multi objective genetic algorithm (MOGA) are used to optimize HEV’s component. 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 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.

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

\textbf{NOMENCLATURE}

\begin{footnotesize}
\begin{align*}
V_{oc} & \quad \text{Battery open circuit voltage (V)} \\
E_o & \quad \text{Battery constant voltage (V)} \\
R & \quad \text{Internal resistance (Ohm)} \\
i & \quad \text{Battery current (Amp)} \\
K & \quad \text{Polarization constant (V/Ah)} \\
Q & \quad \text{Battery capacity (Ah)} \\
\text{Exp} (t) & \quad \text{Exponential zone voltage (V)} \\
\frac{dw}{dt_{(\sim t)}} & \quad \text{Change in watt (W)} \\
V_{charge} & \quad \text{Charging voltage (V)} \\
V_{total} & \quad \text{Total voltage (V)} \\
C_{charge \, co} & \quad \text{Charge constant (Found practically)}
\end{align*}
\end{footnotesize}
1 Introduction

India is a growing market for automobile where the biggest class of consumer is the 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 becomes an economic choice for Indian consumers and for the Indian environment. Government of India is also considering to give subsidy for HEV to motivate consumers to buy HEV, another reason to motivate consumer to buy HEV is that it is more economic than an IC engine because of India's price of fuel is higher than electricity for per kilowatt energy. [1]

Design of HEV component is begun with studying drive cycle of Indian road. Drive cycle
pattern depends on road condition, traffic density, and drive behaviour [5].

There are different standard drive cycle available from different countries e.g. ECE-15, EUDC [28]. These drive cycle are used to estimate size of HEV’s component. Designed HEV’s component might not able to sustain all drive cycle load characteristic because it is designed from standard drive cycle and standard drive cycle data has limited information about load pattern. Limitations are that the standard drive cycle design does not represent rate of acceleration & deceleration and its power, Peak Power Demand & Actual Time of Travelling [2]. Efficient and economic HEV’s component cannot be estimated based on information and analysis from standard drive cycle. Design of Motor, IC engine, Battery is depend 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 component 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 is done to calculate vehicle power requirement [6,7]. Dynamic model of HEV composes all vehicle parameters which will be close to actual performance of vehicle. Variety of drive cycle data is taken while HEV component initial size is to be determined. The optimum component size should be calculated by proper optimization method because direct or meal value estimation will not give solution that works efficiently in all course.[8]

From study of this drive cycle loads a method to estimate size of HEV components which will be also optimized to attain minimum consumption of fuel and battery while fulfilling drive cycle load requirement and so it also makes economic to operate for consumer in terms of Rs / KW.

Different optimization techniques are 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 component optimization.

Genetic Algorithm: Component sizing 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: MOGA 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: Complex solution can be solved by SWARM optimization method. 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: TLBO 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 optimization this method can be useful because normally population size is high and multi objective supposed to be achieved while designing HEV component. 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]

One system is taken in account throughout in paper for all analysis, modelling, simulation which is explained in section 2. Information about real time drive cycle measurement on different Indian roads. Analysis of real time drive cycle is carried out in section 3. Modelling of HEV’s component is done in section 4. In section 5 initial estimation of component 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 component design is done for medium sized 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 with series configuration, and 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 component are connected to the load.

Here rating of IC Engine and Electric motor are 50% of load. Load will be shared by both motor and engine will be 50/50. Rating of IC Engine can be chosen higher to 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.

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 id to be designed. Vehicle which is most economic while running is selected to start drive cycle measurement program. Table 1 shows parameters of selected vehicle.

<table>
<thead>
<tr>
<th>Vehicle Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle HP</td>
<td>128HP</td>
</tr>
<tr>
<td>Vehicle RPM</td>
<td>6000</td>
</tr>
<tr>
<td>Tractive Effort coefficient for Indian roads</td>
<td>0.4 to 0.5</td>
</tr>
<tr>
<td>Mass of Vehicle</td>
<td>1300 Kg</td>
</tr>
<tr>
<td>Rolling resistance coefficient in this case</td>
<td>0.013 (asphalt road)</td>
</tr>
<tr>
<td>Height of CG from ground</td>
<td>87 cm</td>
</tr>
<tr>
<td>Effective radius of tire</td>
<td>29 cm</td>
</tr>
<tr>
<td>Distance between wheels</td>
<td>268.5mm</td>
</tr>
</tbody>
</table>
For the purpose of measurement of drive cycle medium sized car with diesel engine is used. Medium size car are most economical 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 for express from figure 1 it can be said 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 [17].

3.3 Analysis

Table 2 shows data of which are derived from real time drive cycle 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 component should fulfil both load drive cycle characteristic.

<table>
<thead>
<tr>
<th>DC</th>
<th>AS</th>
<th>MS</th>
<th>AT</th>
<th>MT</th>
<th>T</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>106</td>
<td>147</td>
<td>103</td>
<td>143</td>
<td>45</td>
<td>80</td>
</tr>
<tr>
<td>N</td>
<td>63</td>
<td>101</td>
<td>62</td>
<td>98</td>
<td>81</td>
<td>96</td>
</tr>
<tr>
<td>S</td>
<td>71</td>
<td>120</td>
<td>69</td>
<td>117</td>
<td>118</td>
<td>147</td>
</tr>
<tr>
<td>U</td>
<td>29</td>
<td>71</td>
<td>30</td>
<td>68</td>
<td>20</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 3 shows summery 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 during drive cycle parameter calculation. Vehicle’s power calculation like its horsepower requirement,
speed, torque, acceleration and deceleration power.

![Figure 3: Vehicle dynamics](image)

\[
F_{\text{max}} = \mu W_f = \left( \frac{h_f}{L} M_v g \cos \alpha - \frac{h_g}{L} \right) \mu_r (1 - \frac{r_d}{h_g}) \]

Parameters of resistance force are calculated as [19]

- Rolling resistance force
  \[ F_r = Pf_r \cos \alpha \]

- Aerodynamic drag force
  \[ F_w = \rho A f C_D \left( V + V_\infty \right)^2 \]

- Gradient Resistance force
  \[ F_g = M_v g \sin \alpha \]

Figure 3 shows parameters of dynamic vehicle used for equations. This resistance are summed up to get actual power used during vehicle dynamics calculation.

### 4 Modelling of HEV component for analysis

From IRD analysis battery kilo watt requirement, hour requirement, size of motor, size of IC engine and fuel tank is determined. The seizing is done for parallel configuration of HEV which is simulated in MATLAB Simulink. Brushless DC Motor, Lead-Ion Battery, IC Engine same as motor rating is selected. For simulation and modelling of parallel configuration of HEV, modelling equation are mentioned below.

#### 1. Battery charging, discharging model [21]

- Discharge
  \[ V_{\text{OC}} = E_0 - R_i (t + i) + K \frac{Q}{Q-i} \text{Exp}(t) \]  

- Charge
  \[ V_{\text{charge}} = \int \frac{dw}{dt} \times \frac{w}{v} \times V_{\text{total}} \times C_{\text{charge constant}} \text{dt} \]

- SOC Calculation
  \[ Q_{ut} = V \times I \times (t) = V I H \]
  \[ Q_{ut} = W \times I \times (t) = W H \]
  \[ K = \frac{Q_{ut}}{Q_{ut}} \times 100\% \]

#### 2. Brushless DC motor model [23]

Electrical Parameters Used In Equations

<table>
<thead>
<tr>
<th>Electrical Parameter</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) HP, W – T</td>
<td>1 HP = 740 W</td>
</tr>
<tr>
<td>Watt</td>
<td>[ \frac{HP}{740} ]</td>
</tr>
<tr>
<td>Torque</td>
<td>[ \frac{watt}{2 \pi \times W_{sync}} ]</td>
</tr>
<tr>
<td>(2) P, V – I</td>
<td>[ P = \frac{V}{I} ]</td>
</tr>
<tr>
<td>IS</td>
<td>[ \frac{P}{V} ]</td>
</tr>
<tr>
<td>(3) T, N, B, R, I, L</td>
<td>[ L_{in} = 2 N_m N_B R_{ro} I_s ]</td>
</tr>
<tr>
<td>T</td>
<td>[ 2 L_{in} N_m N_B I_s ]</td>
</tr>
<tr>
<td>(4) I, N, B, \mu, g</td>
<td>[ L_g = \frac{2 \mu \mu_{co} L_{in} N^2}{g + \frac{N_m}{\mu_r c_{co}}} ]</td>
</tr>
<tr>
<td>CΦ</td>
<td>[ \frac{A_m}{A_g} \approx 1 ]</td>
</tr>
</tbody>
</table>

### Mechanical Parameter

\[ T = \int \frac{d\omega_m}{dt} + T_L + B \omega_m \]
\[ \omega_m = \int \frac{T - T_e}{J} \, dt \]  \quad \text{...(19)}
\[ T_m = \frac{P}{\omega_m} \]  \quad \text{...(20)}

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]
\[ B_{\text{HP}} = \frac{P \times A \times L \times N \times n}{60} \]  \quad \text{...(21)}
\[ P_i = \text{Indicated mean effective pressure} \]
\[ A = \text{Bore area} = 0.05 \]
\[ L = \text{Length of displacement} = 0.065 \]
\[ N = \text{R.P.M.} = 6000 \]
\[ n = \text{Cylinder} = 4 \]

5. Fuel tank model
By calorific value model
Total energy in car,
\[ \text{Diesel calorific value} = 46000 = D_{\text{cal}} \]
Tank capacity = 22.5 = \( T_c \)
Time (hr) = 3600 = \( T \)
\[ D_{\text{cal}} \times T_c \times T = 3.726 \times 10^9 \text{ Calorie} \]
From this analysis it is might not be possible to fulfil all three requirements by mean value.
Because multi objective are to be met by resultant values
Initial sizing is done in 5th section and compatibility is checked in model made in MATLAB Simulink.

5 Influence of drive cycle in HEV component sizing
The main consideration of component in HEV are battery storage, power of electric machine and size of IC engine and it’s fuel tank capacity. All this components mainly determines its initial cost of HEV power train and vehicle fuel/battery consumption.

To determine component size of HEV first step is to collect data of real time drive cycles of roads where HEV is to be used. Constraint of design parameter of HEV component size is to be determined by drive cycle data.

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

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

Deceleration energy is also considered for designing 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.

Deceleration power will also determine battery power rating because in urban road type drive cycle where deceleration energy higher there rate of recharge of battery will be higher. [20]

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 estimated size is

Motor rating = 60hp
IC engine rating = 60hp
Battery rating = 22.7kw
Fuel Tank = 22lit.

Initial estimating 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.

From this initial estimated data component size optimization will be done with constraint.
Component size should sustain drive cycle characteristic of all roads and highways. From drive cycle analysis we have to determine best value of HEV component they could sustained load characteristic of drive cycle and our four requirements mentioned below

(i) Drive cycle load requirement should be met
(ii) Consumption of fuel and battery should be minimum.
(iii) Battery should not discharge after full charge before reaching charging station.
(iv) Component should sustained characteristic of all drive cycle reasonable. Characteristic like acceleration power requirement, deceleration power should be harvested and top speed should be met reasonably following drive cycle load characteristic.

Two optimization methods were used to determine component size. First is multi objective genetic algorithm and second is teaching and learning based optimization. Genetic algorithm is done by alternate objective function.

Reason of using two optimization method is to compare result of TLBO with another used method to see effectiveness of TLBO method for HEV’s component size optimization.

MOGA [26] is Genetic Algorithm method that used to fulfil multi objective solution form population. There are different methods used to achieve optimal solution and reduce conflict among objectives. Flow chart of the method is shown in figure number 6. Functional equations for MOGA are

**Mutation Function**

\[
f(x) = g \left[ \frac{P_{avgS}}{\sum n} \frac{P_{avgH}}{\sum m} \frac{P_{maxS}}{\sum n} \frac{P_{maxH}}{\sum n} \frac{P_{nt}}{\sum m} \frac{P_{nk}}{\sum m} \right] \quad (22)
\]

- \( P_{avgS} \) = Avg. Speed
- \( P_{avgH} \) = Avg. H.P.
- \( P_{maxS} \) = Max. Speed
- \( P_{maxH} \) = Max. H.P.
- \( P_{nt} \) = Time
- \( P_{nk} \) = K.M.

\[ m \neq n \]

\[ \sum n = \sum m \]

\[ n = 1,2,3,4, \text{ (gene pool)} \]

\[ m = 1,2,3,4, \text{ (gene pool)} \]

\[ g = \text{Tolerance of (0.95 \to 0.99)} \]
Cross Over Function

\[
 f(x) = g \left[ \frac{P_{\text{navg}}}{\sum m}, \frac{P_{\text{navg}}}{\sum m}, \frac{P_{\text{min}}}{\sum m}, \frac{P_{\text{max}}}{\sum m}, \frac{P_{\text{max}}}{\sum m}, \frac{P_{\text{max}}}{\sum m} \right] \quad (23)
\]

\[ m \neq n \]

\[ n = 1,2,3,4, \text{ (gene pool)} \]

\[ m = 1,2,3,4, \text{ (gene pool)} \]

\[ g = \text{Tolerance of } (0.90 \rightarrow 0.99) \]

- Constraints

\[ g(x) > f(x) > g'(x) \]

\[ g'(x) = [70, 144, 68, 118, 85, 99] \]

\[ g(x) = [100, 160, 120, 140, 186, 235] \]

In MOGA there are four fitness criteria, four are mentioned in this section. Input variable are as shown in table number 2. Population data will go through fitness function to find fittest value which fits the fitness criteria. This will determine by two processes (i) cross over (ii) mutation. From both the fittest value selected and will be simulated in MATLAB to find its sustainability for different load drive cycle requirements mentioned in this section.

Second method of optimization is teaching and learning based optimization (TLBO). Optimization process algorithm is mentioned below. [14,15]

This method is divided in two parts (i) teacher phase (ii) learner phase. Drive cycle data becomes learners, teacher becomes best solution before optimization and our criteria which are four requirements mentioned in this section and HEV component sustainability to load characteristic drive cycle becomes criteria to be fulfilled and initial solution which is mean of population becomes teacher and that solution becomes starting point of optimization.

(i) Teacher Phase

\[ M_{\text{Mean}} = r (M_{\text{N}} - T F) \quad (24) \]

\[ S_0, \quad M_N = M_{\text{Mean}} - T F \quad (25) \]

\[ r_i = [0,1] \text{ selected randomly.} \]

In teacher phase new values are derived randomly depends on value of \( r_i \). Old solution is modified by new solution and new solution becomes starting point for learner phase.

(ii) Learner Phase

For \( I = 1 : D_n \)

Randomly select two learners \( M_i \) and \( M_j \), \( i \neq j \)

If \( f(M_i) < f(M_j) \)

\[ M_{N_i} = M_{\text{opt}} + r_i (M_{j} - M_{i}) \quad (26) \]

If \( f(M_i) > f(M_j) \)

\[ M_{N_i} = M_{\text{opt}} + r_i (M_{i} - M_{j}) \quad (27) \]

Accept \( M_N \) as new solution and check if it brings results within criteria. If criteria are not fulfilled than teacher phase will be started again. TLBO method not only selects optimized value from population but it also modifies values from population to make optimization more efficient toward goal.

By TLBO method optimized value is taken and from that HEV components are sized and simulated in MATLAB and results is shown in table number 4.

Figure 7: Algorithm of TLBO
Table 4: Result of optimization method

<table>
<thead>
<tr>
<th>Optimization Method</th>
<th>AS</th>
<th>MS</th>
<th>AH</th>
<th>MH</th>
<th>T</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Value Result</td>
<td>70</td>
<td>114</td>
<td>68</td>
<td>118</td>
<td>85</td>
<td>99</td>
</tr>
<tr>
<td>TLBO Result</td>
<td>84.75</td>
<td>124</td>
<td>82.75</td>
<td>120.75</td>
<td>81.5</td>
<td>96</td>
</tr>
<tr>
<td>MOGA Result</td>
<td>106</td>
<td>147</td>
<td>103</td>
<td>143</td>
<td>81.5</td>
<td>96</td>
</tr>
</tbody>
</table>

Table 5: Rating from result of optimization

<table>
<thead>
<tr>
<th>Optimization Method (Final Rating)</th>
<th>Motor (HP)</th>
<th>IC Engine (HP)</th>
<th>Battery Rating (kw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Value</td>
<td>60</td>
<td>60</td>
<td>22.7</td>
</tr>
<tr>
<td>TLBO</td>
<td>45</td>
<td>45</td>
<td>21.5</td>
</tr>
<tr>
<td>MOGA</td>
<td>50</td>
<td>50</td>
<td>21.5</td>
</tr>
</tbody>
</table>

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 convetional 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

<table>
<thead>
<tr>
<th>Car Type</th>
<th>Rs/KM</th>
<th>Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC Engine</td>
<td>3.005</td>
<td>Express highway</td>
</tr>
<tr>
<td>HEV</td>
<td>1.45</td>
<td>Express highway</td>
</tr>
</tbody>
</table>

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

8 Results

Table 7,8,9 shows result of different optimization method. Mean Value result 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 improvement in efficiency in IC engine which is less efficient component in any HEV.

Compared with MOGA method of optimization TLBO method shows higher efficient operation but 1.5% in RPM.

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

<table>
<thead>
<tr>
<th>Optimization Method</th>
<th>HP</th>
<th>Battery SOC %</th>
<th>Fuel Left %</th>
<th>RPM Drop %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Value Result</td>
<td>120</td>
<td>76.08</td>
<td>40.12</td>
<td>0</td>
</tr>
<tr>
<td>MOGA Optimization Result</td>
<td>98</td>
<td>77.26</td>
<td>44.66</td>
<td>2.5</td>
</tr>
<tr>
<td>TLBO Optimization Result</td>
<td>90</td>
<td>78.7</td>
<td>51.12</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 8: For urban highway

<table>
<thead>
<tr>
<th>Optimization Method</th>
<th>HP</th>
<th>Battery SOC %</th>
<th>Fuel Left %</th>
<th>RPM Drop %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Value Result</td>
<td>120</td>
<td>98.06</td>
<td>99.47</td>
<td>0</td>
</tr>
<tr>
<td>MOGA Optimization Result</td>
<td>98</td>
<td>98.19</td>
<td>99.51</td>
<td>2.5</td>
</tr>
<tr>
<td>TLBO Optimization Result</td>
<td>90</td>
<td>98.25</td>
<td>99.57</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 9: For express highway

<table>
<thead>
<tr>
<th>Optimization Method</th>
<th>HP</th>
<th>Battery SOC %</th>
<th>Fuel Left %</th>
<th>RPM Drop %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Value Result</td>
<td>120</td>
<td>92.64</td>
<td>40.12</td>
<td>0</td>
</tr>
<tr>
<td>MOGA Optimization Result</td>
<td>98</td>
<td>92.9</td>
<td>90.33</td>
<td>2.5</td>
</tr>
<tr>
<td>TLBO Optimization Result</td>
<td>90</td>
<td>92.81</td>
<td>51.12</td>
<td>4</td>
</tr>
</tbody>
</table>
9 Conclusions
Drive cycle measurement 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 dynamic model of parallel HEV. 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 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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