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Modeling of Vehicular Based Electric Power Generation System Using MATLAB/Simulink

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ABSTRACT

In the recent years the energy generation and usage pattern of a country has gained an importance in deciding the economy and overall growth of the country. But usage of electricity is ever increasing demand on the existing generating infrastructure. Due to several limitations and constraints related to new power plants they are not becoming economic. This result in ever increasing short fall of energy, in this regard several substitute's namely renewable and other generation are playing marginal role. This is due to their high initial cost of installation. In this regard vehicular generation is one of the promising solutions as vehicle to grid concept is under practice. In case of electric vehicles, when ever coasting down regeneration is noticed and it supplement to the battery energy. Similarly an opportunity to generate electricity from conventional vehicles and others is worked out by suitably representing the parameters related to the vehicles. This research strongly proposes the generation of electricity from moving vehicles by incorporating additional generating and storing infrastructure on the vehicle. The performance analysis of the selected vehicles with respect to the fuel consumption is recorded. The comparative analysis of the results provides sufficient evidences to the proposal with a negligible change in fuel consumption for various trials with change in cargo load. In the present work cost and payback like computation for the proposal are not worked out. With this simple transport owner become power trader and support the national grid with suitable interfaces to the grid.

Keywords:- vehicular generation, modeling, Regenerative energy, vehicle to grid, PHEV, EV

1.INTRODUCTION

India currently imports approximately half of its petroleum products and the percentage is predicted to increase. Petroleum which is imported, two-thirds of it is used by the transportation sector. By using of alternative fuel or by improving the automobile efficiency the dependence on foreign oil can be minimized. In coming years significant challenges will have to be faced by the Indian government in meeting its energy demands [1].

The availability of power in India has both increased and improved but demand has increased substantially and peak shortages prevailed in 2009-10 [1]. By the end the year 2012 one lakh Mega Watt of power generation had to be met but due to various constraints the demand hasn't been met. India has set a target of 40000MW of power to produce through solar photovoltaic system by 2022 of which 10000MW during 2015-16 to 2017-18 [2]. During the fiscal year 2014-15, power generated was 1,030 billion KWh with a short fall by 38.138 billion KWh. The electrical power demand in the year 2016-17 is expected to be 1,392Tera Watt hr, with a peak demand of 218GW [3]. And in coming years 2021-22 peak demand is expected to increases by 298GW [3]. Therefore to meet the energy crisis various solutions like renewable solar/wind integration and Vehicle to grid integration (V2G) are coming into picture.

When vehicle power is used to generate electric power and then it is fed to the electric grid through storage devices it is referred as Vehicle to Grid (V2G). The concept of V2G has been implemented in developed countries USA, UK and Japan, where PHEV, EV are used for V2G technology. Vehicles, whether fueled by battery or by liquid or gaseous have the capacity of generating electricity. The power capacity of current internal-combustion engine has been under-utilized [4, 5].

For example in US the vehicle fleet has over ten times the mechanical power of all the current United States electrical generating power plants and these are almost 95% idle in a day [4]. These electric utilities could use the electric or battery vehicle as storage or hybrid (PHEV) or a conventional vehicle with additional generating infrastructure to provide them the electric power. The passenger vehicle fleet has ten times the capacity of nation's electric generation equipment [5].

If significant fraction of automotive fleet were powered up it would dwarf the generation capacity of electric utilities, at lower capital cost and comparable availability. Studies on magnitude of vehicle fleet have shown the potential of substantial amount of power can be generated from the vehicle fleet. if we could consider 2/3rd of the vehicle fleet were

garaged and only a half of it is used for discharging power then the vehicle fleet would be able to put up to1.3×10^{10} Watt or 13 Giga Watt of energy to the electric utilities [4]. Previous Studies have shown that a single vehicle have the potential of producing 10kW of power which is sufficient to power ten homes [5].
The amount of fuel consumed by the vehicle and the power plants are similar because the vehicle fleet's power is sitting idle so much more than the utility generation equipment [4]. In this paper the amount of energy that can be generated using conventional vehicles and hybrid electric vehicles (HEV's) is computed using the Matlab/Simulink vehicle models. Further the effect on fuel consumption in conventional vehicle due to additional power generating infrastructure is analyzed.

2.COMPUTATIONAL STUDY

The various aspects related to the vehicle parameters such as fuel consumption, energy usage, vehicle specification, vehicle type, effect on fuel consumption due to additional Mass on the vehicle are simulated and results are obtained using the Simulink models written in the MATLAB/Simulink environment.

A.Modeling of Vehicles

To compute the amount of energy available in the vehicles, a hybrid vehicle and a conventional vehicle is modeled in MATLAB based on the vehicle specification.
A HEV (Hybrid Electric Vehicle) is a type of electric vehicle which combines a conventional IC engine propulsion system with an Electric-propulsion system. Based on the energy storage sources used to provide supplementary power it is categorized into two types viz: 1.Series hybrid 2.Parallel hybrid.
In series hybrid vehicles electrical machines supply all the tractive energy and there are no mechanical connections between the ICE and the wheels. An ICE in a series HEV provides power to drive the generator to generate electricity but not to propel the vehicle directly. All of the power required to propel a series HEV comes from the electric motor.
In a parallel HEV, both the internal combustion engine (ICE) and electric motor can provide power to propel the vehicle directly, which means that the hybrid power is summed at a mechanical node to power the vehicle. As a result, the size of both motor and the engine can be scale downed, which makes the parallel HEV more viable with lesser costs and higher efficiency. Simulink block of hybrid vehicle is modeled in MATLAB/Simulink. Figure 1 shows the Simulink block model of HEV

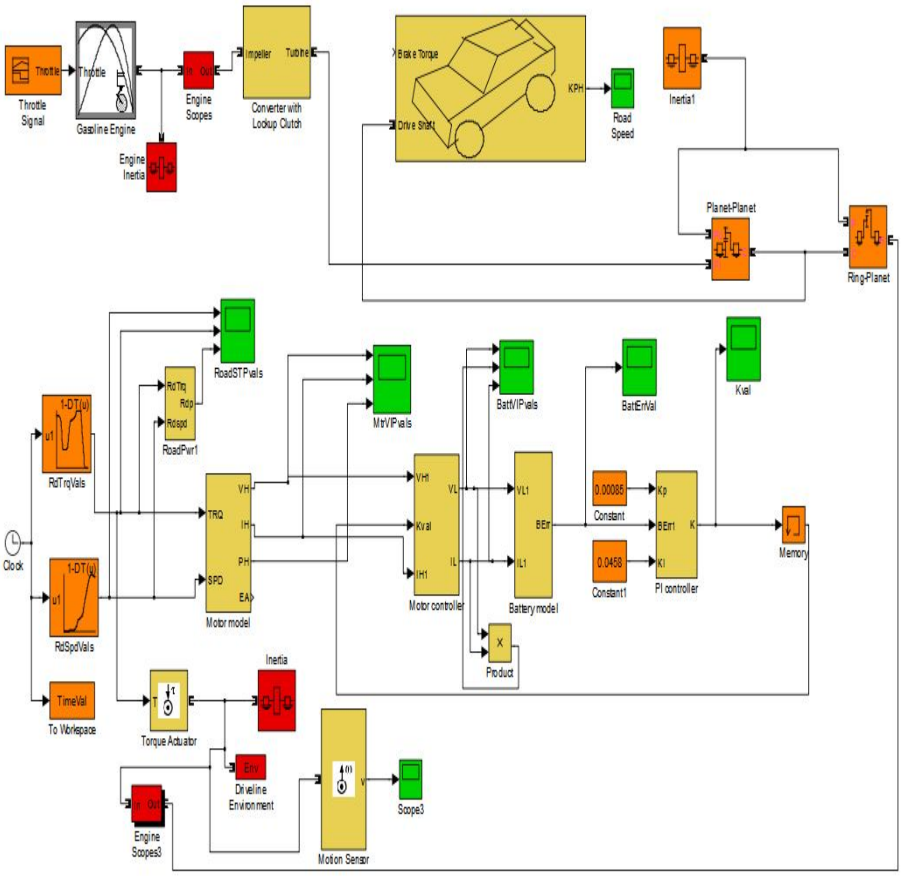

Figure 1: Simulink model of Hybrid Electric Vehicle (HEV)

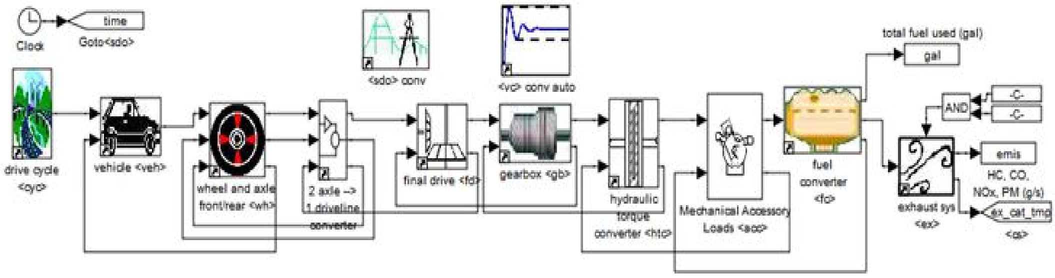

Figure 2: Simulink model of a Conventional Vehicle

Backward- Facing Calculation Path

The left most part of the above Simulink model in figure 2 represents the drive cycle. At this block the various required I/P data; speed v/s Time and road condition for the desired place is given to the next block for simulation. The vehicle and component data which are defined by the MATLAB m-files are used in the appropriate model. “The drive cycle” block transmits the speed trace to the vehicle block.

The vehicle block uses the input to compute the average tractive force and average speed which is required for the next iteration. The computed requirements from the vehicle block are sent to the ‘axle/wheel’ block. At the ‘axle/wheel’ block the transformation of force & linear speed to torque and rotational speed and the effects of tire slip, axle and wheel rotational inertia & wheel and axle bearing drag.

The tire slip model gives the relation between weights on the tyre, longitudinal force, vehicle speed. The slip is given by,

$$slip = \omega_{wh,req} \times r_{wh} / v_{req} - 1 \qquad (1)$$

The above equation gives the relationship of slip neglecting the effect of vehicle speed. (Abbreviation of subscript is given at the end of this paper)

The tire slip is limited to some maximum value, and this limits the transmissible tractive force. By using the vehicle loss parameter’s information borrowed from the ‘vehicle’ block, and according to the acceleration possible with the traction-limited force the required speed is limited. Simultaneously at the maximum slip condition to the maximum force and acceleration is determined by the following equation:

$$dv/dt = F/m \qquad (2)$$

$$F = F_{traction}(dv/dt) - F_{aero}(v) - F_{rolling}(v) - F_{climbing} \qquad (3)$$

$$\omega_{wh,req} = (1 + slip) v_{lim,req} / r_{wh} \qquad (4)$$

By adding up the torque needed for average tractive force, torque required to overcome losses in the bearing and brake drag and the torque required to speed up the wheels and axles rotational inertia the required torque input is computed in Equation 5,

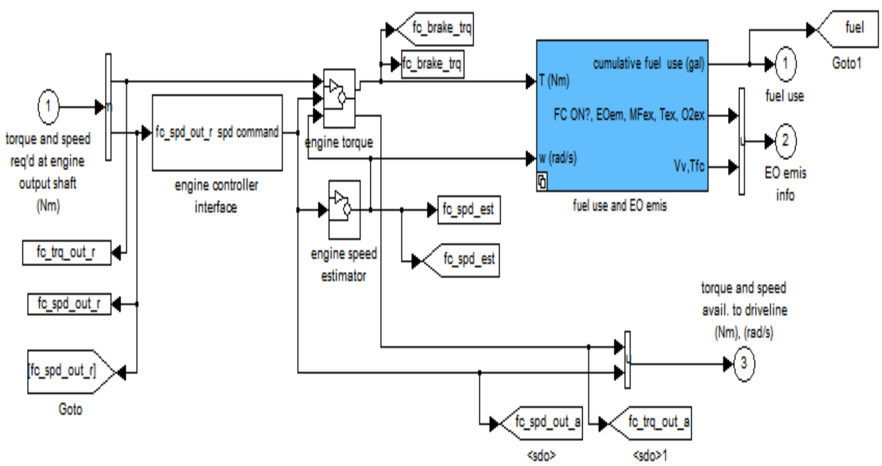

Figure 3: Engine block of Conventional vehicle Modeled in MATLAB/Simulink

$$\tau_{wh,req} = F_{lim,req} r_{wh} + \tau_{wh,loss} + J_{wh}\left(\frac{\Delta\omega_{wh,req}}{\Delta t}\right) \quad (5)$$

The wheel/axle block sends its output i.e. torque and speed required to the final drive block, which further transfers the torque and speed requirements with the vehicle gear ratio and torque loss. Later the gearbox sends the requirements upstream to the motor/controller block in case of a hybrid vehicle.

Motor/Controller block

Figure 4 shows the Simulink block of motor controller. The motor controller block includes loss data, rotational inertia and performance limits. Available torque is calculated using the available power assuming that the ratio of rotor torque to input electric power is same as the achievable or actual situation as calculated for the need.

There are three different performance limits executed in the back-ward facing part of motor/controller block:

a. The required speed is bounded to the maximum motor speed
b. The required torque is confined to the difference between the torque & the motor's max torque required to overcome inertia of the rotor. The torque and speed which are limited are used to interpolate in the motor/controller's input power map.
c. Finally the interpolated power is limited by the motor controller max current limit.

The behavior is depicted in the following equations:

$$P_{mot,in,req} = \min\left(P_{mot,in,map}, I_{con,max} V_{bus,prev}\right) \quad (6)$$

Where,

$$P_{mot,in,map} = f\left(\tau_{mot,lim,req}, \omega_{mot,lim,req}\right) \quad (7)$$

f is the functional relationship described by motor map

$$\omega_{mot,lim,req} = \min\left(\omega_{mot,req}, \omega_{mot,max}\right) \quad (8)$$

And

$$\tau_{mot,lim,req} = \min\left(f_1\left(\omega_{mot,lim,req}\right), \tau_{mot,req} + J_{mot}\left(\frac{\Delta\omega_{mot,lim,req}}{\Delta t}\right)\right) \quad (9)$$

Where,

f_1 is the functional relationship depicted by the motor's torque envelope.

$\tau_{mot,lim,req}$ is the maximum torque capability.

$P_{mot,in,map}$ is the input power required to power the motor at its max limited torque and speed.

$P_{mot,in,req}$ is the power that the motor/controller requires of the power bus which in turn is powered by the batteries/generator.

$$\omega_{mot,act,prev} = \left(v_{act}\left(\frac{\omega_{mot,lim,req}}{v_{avail}}\right)\right)_{prev} \quad (10)$$

The motor/controller efficiency computed during the backward facing calculations is used to compute the torque which can be produced by the motor/controller given the available input power. It is modeled as $\tau_{mot,lim,req}$ / $P_{mot,lim,req}$

$$\tau_{mot,avail} = \tau_{mot,lim,req}\left(\frac{P_{mot,avail}}{P_{mot,lim,req}}\right) - J_{mot}\left(\frac{\Delta\omega_{mot,lim,req}}{\Delta t}\right) \quad (11)$$

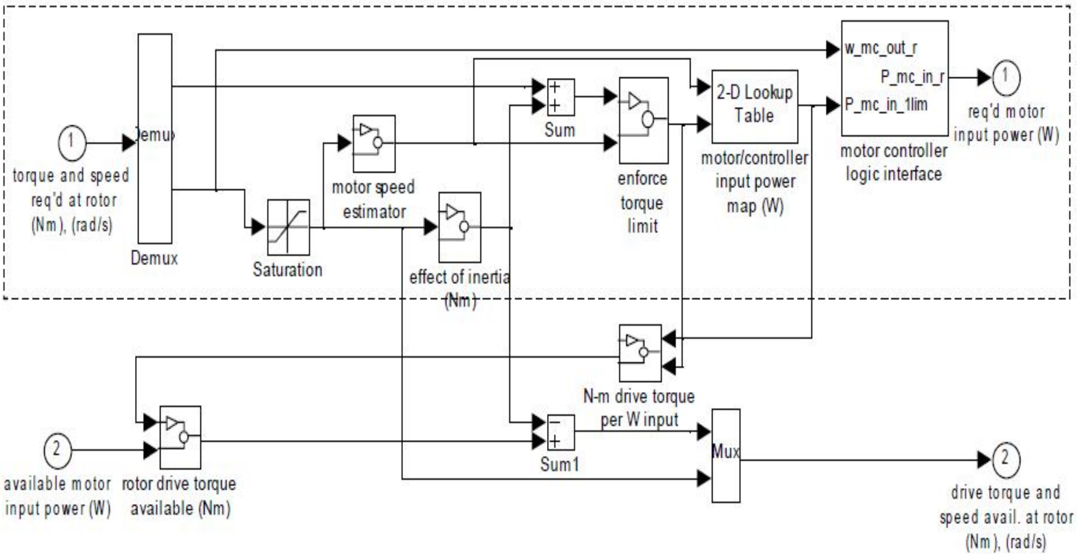

Figure 4: Motor/ Controller Simulink Block model

The available motor torque is transferred by the efficiencies of the gear box and the final drive that results in available torque to drive train and speed input to the wheel/axle.

B.Simulation Studies.

The vehicle models are simulated for different vehicle models with input parameters such as drive train, maximum power and torque, cargo mass, gross vehicle weight (GVW), Motor/Generator rating (in case of hybrid vehicle) and type of drive cycle. The simulation readings, fuel consumption and available regenerative energy are noted. Table 1 and table 2 shows the simulation readings for different vehicles. Table 1 shows the regenerative energy that can be obtained from the vehicles for Indian highway and table 2 shows readings for the Indian urban drive cycle. Figure 5 and Figure 6 shows the drive pattern for Indian Highway and urban road conditions i.e. employed for simulation.

Table 1: Simulation results for Indian highway drive cycle.

Vehicle Type	Engine Rating (kW)	Fuel consumption (liters per 100km)	Distance (km)	Regenerative Mode (kJ)	Gross Vehicle weight (kg)
Hybrid Transit Bus Brand X_1	172, series hybrid	35.8	11.7	10369	16801
Conventional Transit bus	247	41.3	11.7	23742	15663
Hybrid Transit Bus Brand X_2	175, parallel hybrid	34.6	11.7	9835	16789
Hybrid Toyota Prius	43	3.8	11.7	1495	1332
Conventional Heavy truck	135	33.7	11.7	19507	16300

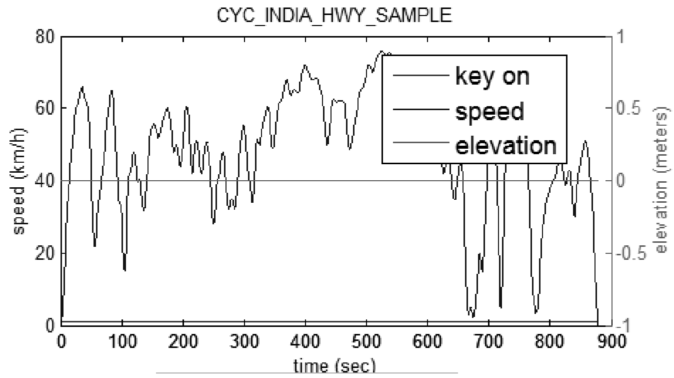

Figure 5: Standard Indian Highway drive cycle

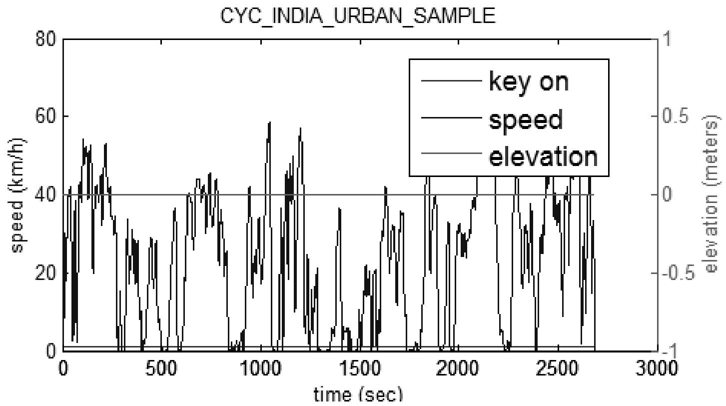

Figure 6: Standard Indian Urban drive cycle

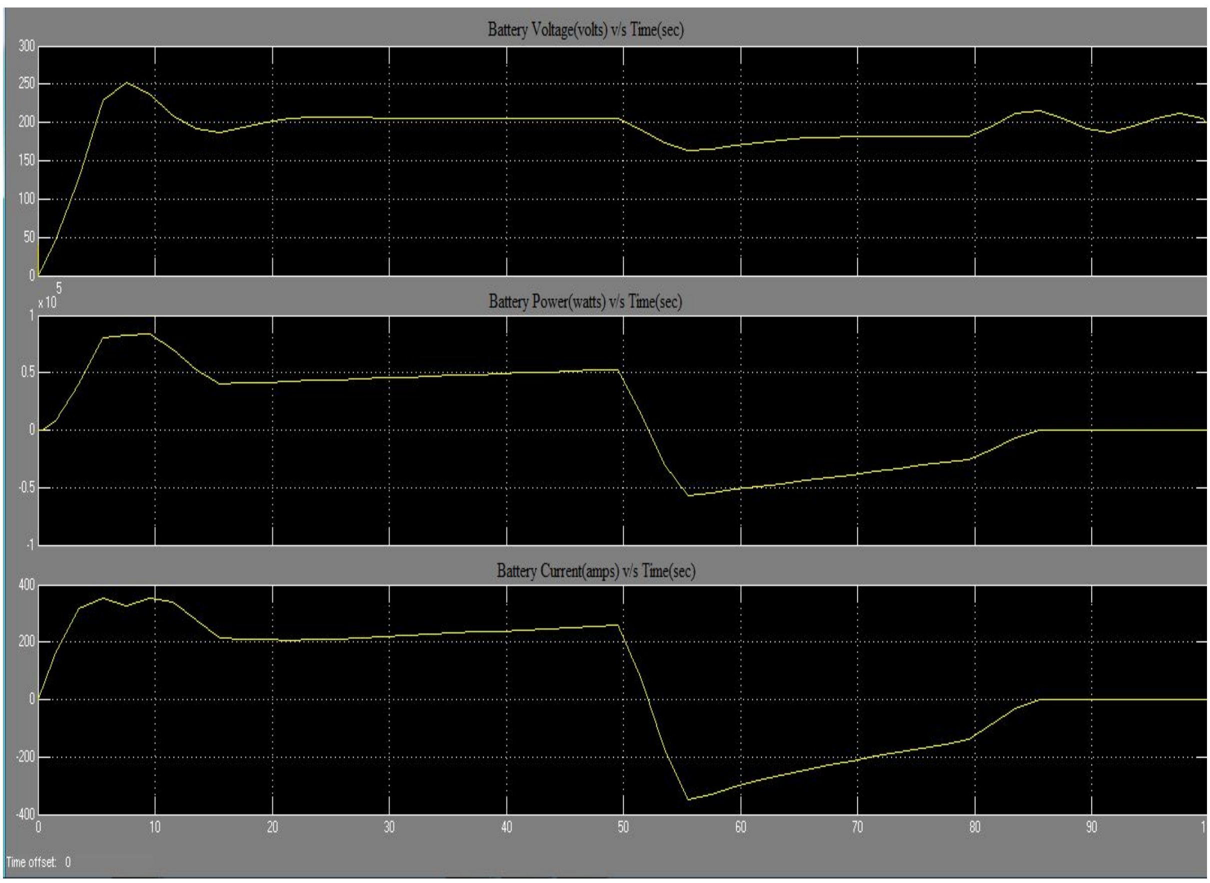

Figure 7: Battery voltage, Power and current for Indian Highway Drive cycle.

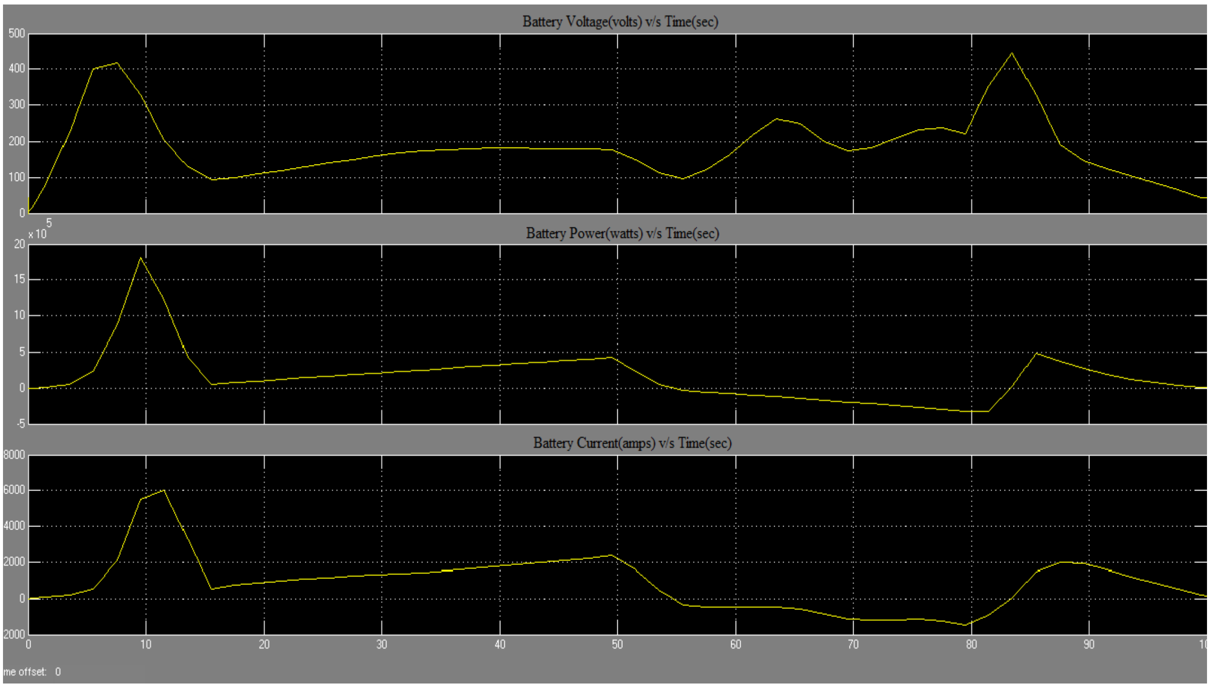

Figure 8: Battery Voltage, Current and Power for Indian Urban Drive cycle.

Table 2: Simulation results for Indian Urban drive cycle.

Vehicle Type	Engine Rating (kW)	Fuel consumption (liters per 100km)	Distance (km)	Regenerative Mode (kJ)	Gross Vehicle weight (kg)
Hybrid Transit Bus Brand X_1	172, series hybrid	50.5	17.4	22349	16801
Conventional Transit bus	247	54.1	17.4	44543	15663
Hybrid Transit Bus Brand X_2	175, parallel hybrid	49.3	17.4	20257	16789
Hybrid Toyota Prius	43	5.3	17.4	2438	1332
Conventional Heavy truck	135	39.7	17.4	37500	16300

From the above studies it is seen that sufficient amount of regenerative energy is available in different vehicle and this can be captured through generating infrastructure and stored in batteries.

C.Effect of Additional Generating Infrastructure Mass on Vehicle Fuel Consumption.

The above Table 1 and Table 2 obtained from the simulation shows the amount of energy that is obtained in the regenerative mode from a vehicle. The available energy can be captured and stored by adding some additional infrastructure. The Infrastructure when incorporated poses some mass on the vehicle; the mass will have effects on the fuel consumed by the vehicle. Therefore to analyze its effect on the vehicle; models are simulated to evaluate the fuel consumption of the vehicle. A simulation is carried out on a Conventional heavy truck. The specification of heavy truck is shown in table 5. Table 3 and 4 shows the fuel consumed by a Heavy Truck before and after addition of generating infrastructure for Indian Highway and Urban drive cycle.

Table 3: Simulation results of a Heavy Truck- Effect of additional mass on fuel consumed for Indian Highway drive cycle.

Engine Rating (kW)	Cargo mass (kg)	F/C L/100km	Regenerative Mode (kJ)	Cargo-mass+300kg (additional infrastructure)	F/C L/100km	Regenerative mode (kJ)
135kW	9000	33.7	19507	9000+300	34.1	19806
135 kW	7000	30.9	17092	7000+300	31.3	17499
135 kW	5000	27.9	14498	5000+300	28.3	14901
135 kW	4000	26.5	13172	4000+300	26.9	13580
135 kW	2000	23.7	10446	2000+300	24.1	10855

Table 4: Simulation results of a Heavy Truck- Effect of additional mass on fuel consumed for Indian Urban drive cycle.

Engine Rating (kW)	Cargo mass (kg)	Fuel Consumed L/100km	Regenerative Mode (kJ)	Cargo-mass+300kg (additional Infrastructure)	Fuel Consumed L/100km	Regenerative mode (kJ)
135kW	9000	39.7	37500	9000+300	40.3	38216
135 kW	7000	36.4	33104	7000+300	36.9	33782
135 kW	5000	33.2	28300	5000+300	33.7	29035
135 kW	4000	31.6	25900	4000+300	32.1	26605
135 kW	2000	28.4	21055	2000+300	28.9	21809

The simulation is carried out for different masses and fuel consumption is noticed. The mass of additional generating infrastructure with the batteries is taken as 300kg. The simulation is carried out for different cargo mass with/without additional generating infrastructure. The results found are convincing which showed a nominal amount of fuel being consumed when additional infrastructure is added. For all the cases the readings of table 3 is simulated for Indian highway drive cycle and table 4 for Indian Urban drive cycle.

In the first case with 9000kgs of cargo 33.7 liter per 100km fuel consumption is observed, whereas with the additional generating infrastructure and the cargo (9000+300kgs) noticed 34.1 liter per 100km; a fuel consumption difference of 0.4 liter/100km in case of Indian highway and 0.5 liters per 100km for Indian Urban drive cycle is observed. Apparently for different cargo weights the simulation readings was taken. Thus, from the above simulation study on fuel consumption of a heavy truck, it clearly defines that with a nominal amount of fuel consumption, vehicle can be used to generate electric power with some additional generating infrastructure. Later this power can be stored in the battery and supplied to grid with micro grid facility.

Table 5: Vehicle Specification of Heavy Truck.

Engine Specification	
Displacement	5883cc
Max Torque	675Nm at 1600rpm
Max Power	135kW at 3000rpm
Vehicle Specification	
GVW (Gross vehicle weight)	31000kgs
Kerb weight	7400kgs

Axle	Multi-axle used for carrying bulkers, goods, tankers

3.RESULTS AND DISSCUSSION

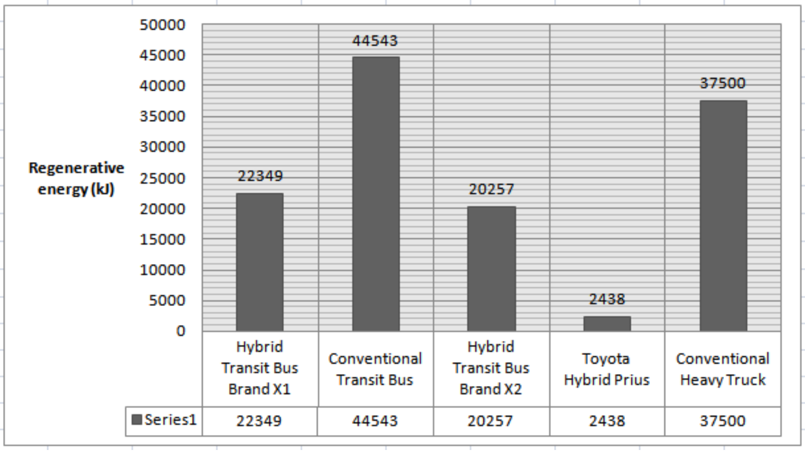

Figure 9: Graph showing energy available from vehicles of different type for Indian Urban roads

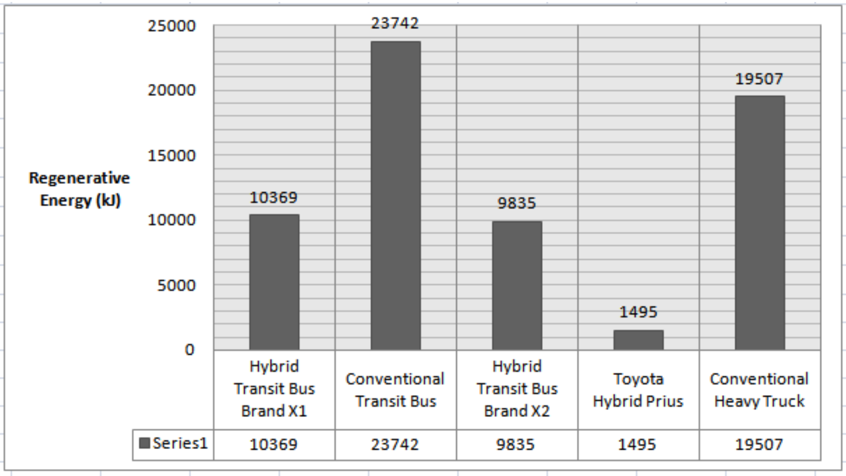

Figure 10: Graph showing energy available from vehicles of different type for Indian Highway roads

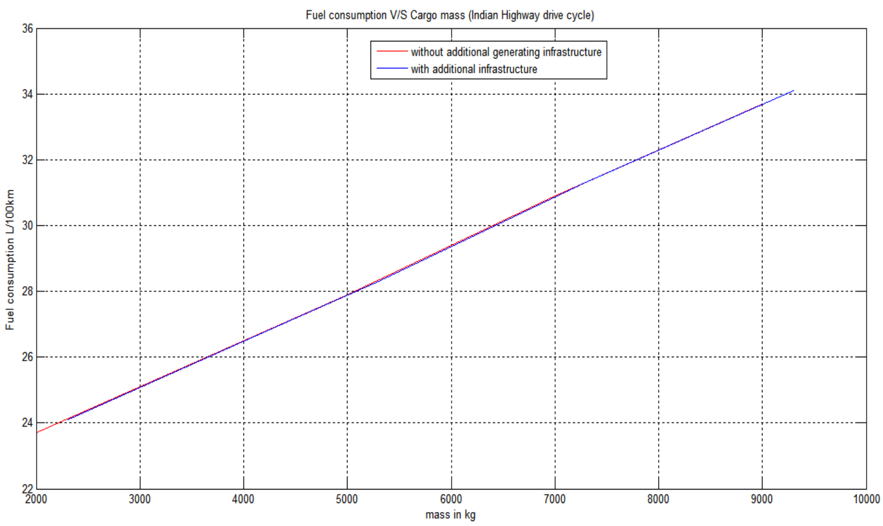

Figure 11 : Effect on fuel consumtion with/without generating infrastructure (Indian Highway drive cycle)

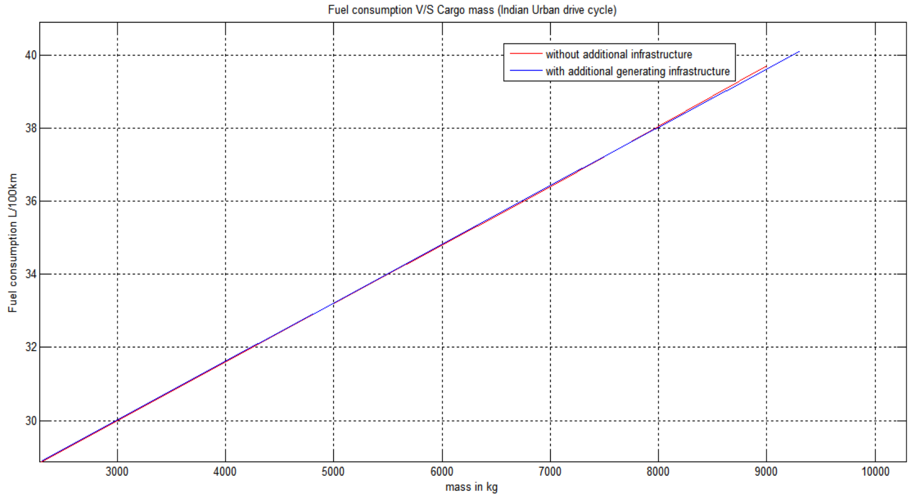

Figure 12 : Effect on fuel consumtion with/without generating infrastructure (Indian Urban drive cycle)

Table 6: Average fuel consumption of a vehicle with and without additional generating infrastructure.

Vehicle Model	Average Fuel consumption (lt/100km)	Average Fuel consumption (lt/100km) with additional loading	Difference (lt/100km)
Indian Highway Drive Cycle			
Heavy Truck (conventional)	28.54	28.94	0.4
Hybrid	25.35	25.67	0.32
Indian Urban Drive Cycle			
Heavy Truck (conventional)	33.86	34.38	0.52
Hybrid	29.85	30.28	0.43

4.Disscussion

1. From Figure 9 & 10 the regenerative energy that has lost in the vehicles of different type and category is plotted. It can be concluded that this available unutilized energy can be captured through generating infrastructure.
2. Comparing figure 8 and figure 9 we see that available energy is higher in case of urban drive cycle, this is due to more braking action in urban road condition.
3. Simulation results show 5kWh to 10kWh of Energy is available in case of conventional heavy truck. This energy can be used for power generation purpose.
4. An simulation conducted on a conventional heavy truck for effects of vehicle fuel consumption due to additional generating infrastructure; shows a nominal fuel consumption difference 0.4 liters' per 100km (in case of Indian Highway) and 0.5 liters' per 100km (Indian Urban) this is shown in figure 11 and 12. The same is also shown in Table 6.
5. In a span of 100kilometer with a nominal fuel consumption of 0.4lt/100km in case of a conventional heavy truck, if we could capture at least 1kW of energy from it then for a certain region or country or state where vehicular based electric generation is implemented for 50,000 vehicles, the vehicle fleet would be able to contribute 50,000kW or 50MW of Electrical power to Electric Utilities.
6. Vehicular based electric power generation is best suited in case of buses, trucks, goods carrier and heavy trucks where substantial amount energy is available and adequate space to provide additional generating infrastructure is available.
7. The captured power from vehicles can be stored in batteries which then later can be supplied to electric utilities through micro grid facility where other generation like wind/solar are integrated.

5.CONCLUSION

The results of modeling and analysis of the various vehicles for the generation of electricity has provided sufficient evidences for the said opportunity. The same was simulated and found working properly and is not possible to generate without the additional infrastructure on the vehicle. Simulation is carried out in MATLAB/Simulink and Vehicular simulation tool. A negligible change in fuel consumption is noticed for the drive cycles applied for the different load levels. In the near future, it's highly possible to have Vehicular distributed kind of generation where-in the transport operators area may be a distributed area of generation. They find significant role in the power industry. The possibility in the coming future is that the interaction of PHEV's, EV and conventional vehicle with the concept of vehicular based power generation and V2G can offer opportunities for the electric utility industry.

Abbreviation of Subscripts

act- actual
avai- available possible given the drive train limits
con- related with the motor controller
lim- subject to a component performance limit
map- calculated from component performance map
mot - associated with the motor or motor/controller set
prev- evaluated in the previous time step
req - required
wh - associated with the wheel or wheel & axle

References

[1]. P. Garg,- "Energy Scenario and Vision 2020 in India", Journal of Sustainable Energy & Environment 3 (2012) 7-17, Ministry of Environment and Forests, CGO Complex, Lodi Road, Delhi, India Copyright @ 2012 By Journal of Sustainable Energy and Environment 7

[2]. Renewable Energy in India: Growth and Targets, Ministry of New and Renewable Energy (MNRE) *13 May 2015.*

[3]. Jyoti D. Vora,- "Power scenario in India – Then & Now: An Insight" 2015.(www.engrreview.com/Article)

[4]. Willet Kempton', Toru Kubo,- "Electric- Drive Vehicle for peak Power in Japan", American Council for an energy efficient economy, 1001 Connecticut Ave, NW, Suite 801, Washington DC, USA August 1999 (Energy Policy 28 (2000) 9-18. Elsevier science LTD)

[5]. Kempton. W and Letendre. S (1997)- " Electric Vehicle as a New Source of Power for electrical utilities", Transpn Res:- D, Vol 2, No. 3, pg 157-175,1997. © 1997 Elsevier Science Ltd. PII: S1361-9209(97)

[6]. Gao D.W., Mi, C., Emadi, A., "Modeling and Simulation of Electric Hybrid Vehicles", Proceedings of the IEEE, Vol.95, issue 4, p.p. 729-745, April 2007

[7]. Karen L. Butler, *Mehrdad* Ehsani, *Preyas* Kamath, - "A Matlab-Based Modeling and Simulation Package for Electric and Hybrid Electric Vehicle Design", IEEE Transactions on Vehicular Technology, Vol. 48, No. 6, November 1999.

[8]. Yutaka Ota, Haruhito Taniguchi, Jumpei Baba, Akihiko Yokoyama- "Implementation of autonomous distributed V2G to electric vehicle and DC charging system, The University of Tokyo, Japan, 2014,© 2014 Published by Elsevier B.V.

[9]. T. Markel, A. Brooker, T. Hendricks, V. Johnson, K. Kelly, B. Kramer, M. O'Keefe, S. Sprik, K. Wipke- "ADVISOR: a systems analysis tool for advanced vehicle modeling", National Renewable Energy Laboratory, Golden, CO 80401, USA, Journal of Power Sources 110 (2002) 255–266, 2002, ©2002 Elsevier Science Ltd All rights reserved. PII: S0 378 - 7753 (02) 00189–1)

[10]. R. Noons, J. Swann, and A. Green, "The use of simulation software to assess advanced powertrains and new technology vehicles," in Proc. Electric Vehicle Symp. 15, Brussels, Belgium, Oct. 1998.

[11]. Alec Brooks, Tom Gage,- "Integration of Electric Drive Vehicles with the Electric Power Grid - a New Value Stream". Paper presented at the 18th International Electric Vehicle Symposium and Exhibition, 20-24 October 2001, Berlin, Germany

[12]. David Hawkins,- "Vehicle to Grid— A Control Area Operators Perspective." Presentation at the EVAA Electric Transportation Industry Conference, Sacramento, CA, December 2001

[13]. W. Kempton, J, Tomic, S. Letendre, A. Brooks, and T. Lipman.- "Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in Califomia." Davis, CA: Institute of Transportation Studies Report , 2001