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# Topographical Inertial Energy Simulator for Hybrid Electric Transit Vehicles

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**Abstract**

There is a critical need for improved vehicle performance simulation tools in order to optimize the design and selection of drive components for hybrid electric transit vehicles. A Topographical Inertial Energy Simulator (TIES) has been developed as a design tool that incorporates topography and curvature of the planned route, vehicle weight, requirements for acceleration and instantaneous speed, aerodynamic drag and rolling resistance, and overall energy efficiencies for each of the components that make up the drive train of a hybrid transit vehicle. When used in conjunction with models of the energy conversion processes required to charge and discharge electrical components (batteries and ultracapacitors) and models of the overall "well to wheel" efficiency characteristics of petroleum based fuels, TIES can be used to compare predicted performance of hybrid electric transit vehicles that use various combinations of internal combustion engines, fuel cells, ultracapacitors, and batteries.

*Keywords: simulation, energy consumption, public transport*

## 1 Introduction

The Topographic Inertial Energy System is a model for hybrid and battery electric vehicles. TIES uses a path of coordinates on a topographic map to record vehicle latitude, longitude, and elevation. This indicates when the vehicle is on a hill or making a turn. It calculates the primary five forces in vehicle movement including acceleration, deceleration, aerodynamic drag, rolling resistance, and elevation changes. Using these forces, instantaneous speed, and interval time, the energy usage can be found. From energy usage, a number of predefined efficiencies and protocols are used to measure the energy consumption. This also includes the effects of regenerative braking.

The instantaneous speed is the most dynamic portion of this model. The speed algorithm determines the instantaneous speed by using the sharpness (˚/ft) of the upcoming curve, acceleration profiles, and the speed limit. This takes place iteratively and scans the topographic data ahead of the energy model. This paper provides an overview of TIES being used to evaluate and compare hybrid and alternative fuel vehicles.

## 2 Background

The development of TIES began as CETE evaluated advanced vehicle technologies and alternative fuel options for a proposed route in the Cades Cove area of the Great Smoky Mountains National Park. The National Parks Conservation Association (NPCA) was attempting to identify a clean vehicle technology to serve this congested area of the park. The TIES was developed to assist with this process and the model was able to evaluate diesel, hybrid electric and other alternative fuel shuttles.

The first model was very simple and utilized a string of data points which recorded the elevation and distance traveled. The model used a constant speed to determine the power required to overcome adverse forces over each interval. These forces include aerodynamic drag, rolling resistance, and changes in elevation. The interval power was then used to determine the energy usage. The interval power can also determine if the vehicle is underpowered to maintain the average speed.

The second revision of the model featured regenerative braking, a more accurate rolling resistance calculation, and variable air density. Regenerative braking used a constant efficiency to model charging the batteries while the vehicle moved down a hill. The air density and aerodynamic drag decrease as the vehicle's elevation increases. Air density was calculated for each interval, and used in that interval's aerodynamic drag calculation.

The next revision was designed to simulate a vehicle during the Altoona Test Cycle, a Federal Transit Administration (FTA) prescribed bus testing procedure. This test has no elevation change, and is an effective test for accuracy of the model's rolling resistance and aerodynamic drag calculations. This was the first version of the model with variable speed. It introduced an energy calculation for moderate vehicle acceleration and deceleration.

The fourth revision was created to model the the existing University of Tennessee at Chattanooga campus MocsExpress shuttle route. This route assists UTC students in moving around campus. The route also has hills which approach a 12% grade. This revision reintroduced elevation change into the model. Acceleration and deceleration were also used for turns and stops. The speed was variable, but it was manually entered for each interval. Idle fuel consumption was also added since the shuttle bus stops for several seconds at each stop.

# 3 Current Model

The TIES is now a spreadsheet with several visual basic scripts. Global positioning system (GPS) coordinates are recorded along a route in Sevierville, TN. Latitude, longitude and elevation are used to determine hills, curves, and turns in the route. The speed algorithm adjusts the vehicle speed to maintain a comfortable ride. It uses the shape of the coordinates, local speed limits, and vehicle limitations to arrive at a suitable speed for each interval.

Interval speed is used to find the power required to overcome counter forces. The following four equations are used to calculate these forces.

$$F_{elev} = mg\frac{\Delta e}{\Delta d} \qquad (1)$$

$$F_{roll} = \mu_r mg\frac{\sqrt{\Delta d^2 + \Delta e^2}}{\Delta d} \qquad (2)$$

$$F_{drag} = \frac{\rho}{2}v^2 C_d A_f \qquad (3)$$

$$P_{inertia} = \frac{1}{2}m\Delta v^2 \qquad (4)$$

The following table defines each variable used in formals 1 through 4.

Table 1: Variable definitions

| Variable | Definition |
|---|---|
| m | Vehicle Mass |
| g | Gravitational Force |
| e | Elevation |
| d | Distance Travelled |
| $\mu_r$ | Coefficient of Rolling Friction |
| $C_d$ | Coefficient of Aerodynamic Drag |
| $A_f$ | Frontal Area |
| $\rho$ | Air Density |
| v | Current Speed |

The forces are multiplied by the velocity, and the powers are summed. If $P_{inertia}$ or $F_{elev}$ is negative, it is multiplied by the regenerative braking efficiency. Energy usage is calculated with the total power usage and interval time. This is the energy required to move the vehicle. It is now multiplied by the traction efficiency to find the energy consumption.

# 4 Results

The results of the calculations for Sevierville, TN are below. Figure 1 is an example of the power draw for each of the four counter forces. The interval shown contains a wide variety of elevation and speed changes.

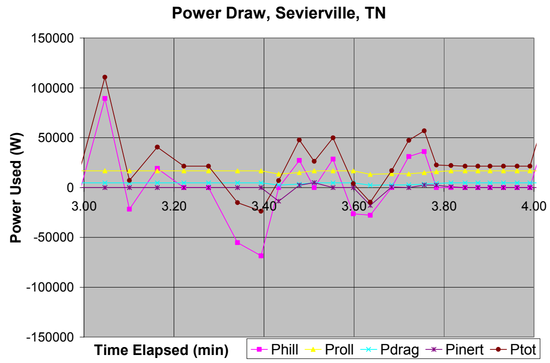


Figure1: Power Draw over Time

Table 2 contains most of the variables from the vehicle which is being modelled. Other inputs not shown include GPS coordinates, local speed limits. Table 3 contains the tabulated outputs for the TIES while modelling the Sevierville route.

Table 2: TIES Inputs, Sevierville, TN

| Input Value | SI | SAE |
|---|---|---|
| Vehicle Mass | 7257.5 kg | 16000 lbs |
| Rolling Resistance | 0.015 | |
| Drag Coefficient | 0.36 | |
| Frontal Area | 7.87 $m^2$ | 84.67 $ft^2$ |
| Air Density | 0.865 $kg/m^3$ | 0.054 $lbm/ft^3$ |
| Regeneration Efficiency | 0.66 | |
| Traction Efficiency | 0.78 | |

Table 3: TIES Outputs, Sevierville, TN

| | | |
|---|---|---|
| Distance | 12.00 km | 7.46 mi |
| Time | 1079 s | 17.98 min |
| Energy Usage | 26.10 MJ | 24736 Btu |
| Energy Consumption | 33.46 MJ | 31713 Btu |
| Energy / distance | 2.79 MJ/km | 4253 Btu/mi |
| Energy / time | 1.86 MJ/min | 1764 Btu/min |

The flexibility of the TIES allows the user to quickly modify variables and perform sensitivity analyses. Figure 2 depicts a sensitivity analysis performed on regenerative braking efficiencies of 0%, 35%, and 70%.

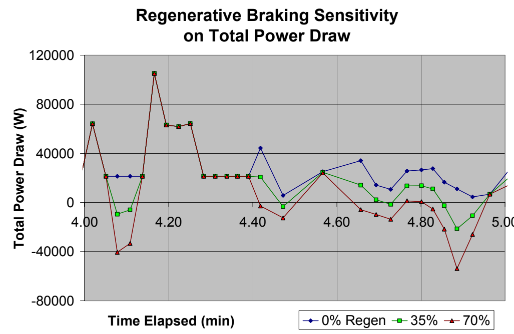


Figure2: Regenerative Braking Sensitivity

## 5 Further Advancements

The TIES is undergoing further advancements which include GIS integration, engine and drivetrain emulators, and stoplight probabilities. Geographic Information System (GIS) integration involves writing a program to record GPS coordinates from a reliable source. The end product would have inputs for multiple waypoints. Current model inputs, speed limit, and road condition would be recorded with adjustable interval lengths. Modeling a vehicle with a standard internal combustion drivetrain requires more inputs. Further revisions of the TIES will include calculations for combustion efficiencies and transmission gearing.

The current model does not stop the vehicle for stoplights. More information about the route would allow the TIES to stop along the route. A simple probability would be assigned to each road at different times during the day. This will be used to vary the results for each run of the model.

## 6 Conclusion

The Topographic Inertial Energy System is a model for hybrid and battery electric vehicles. It uses vehicle latitude, longitude, and elevation along a pathway. A speed algorithm maintains comfortable ride while maintaining the speed limit. The vehicle speed, topography, and other inputs are used to calculate the interval power required by the vehicle's drivetrain. This includes the effects of regenerative braking. Energy usage is calculated from the interval power requirements. The final product of the TIES is the energy consumption of the vehicle's drivetrain. TIES played an instrumental role in evaluating advanced vehicle technologies and alternative fuel options in several practical applications during the past year.

Future revisions of the TIES will enhance usability and accuracy. GIS integration will make entering routes much easier. Engine and drivetrain simulations will allow the comparison between different fuels or engine alternatives such as fuel cells. A more advanced speed algorithm will better approximate the vehicle's real world behaviour. All these advancements will produce a viable tool for selecting the proper vehicle for a transit route.

# References


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