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SIMULATION OF ELECTRIC VEHICLE AND COMPARISON OF ELECTRIC POWER DEMAND WITH DIFFERENT DRIVE CYCLE

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ABSTRACT

Electric vehicles are gaining popularity and power and different analysis are performed on a simulated electric vehicle .This paper presents a method to model and simulate an electric vehicle according of newton's law of motion. Dimension analysis will be used to find power and energy required to propel the forward at specified drive profile.

Keywords: Drive Cycle, Electric Vehicle, Modelling, Power and Energy Requirement, Simulation

I INTRODUCTION

This paper contributes to develop a method to model and simulate electric vehicle very simply by using modified equations derived from newton's law of motion. Electric vehicles are getting very popular due to several reasons like environmental impacts of Internal Combustion Engine (ICE) based vehicle, rapidly increasing fuel cost and depleting fossil fuel reserves. Also lot of research are going in this field to develop better subsystems of electric vehicle example hybrid energy storage system, power train components, mechanical power transmission mechanism system etc. For the development of any such system need to accurately model and simulate electric vehicle if essential and this paper contributes for that. Also this model can be used for battery sizing according to peak power demand vehicle required to cater. Drive range of vehicle for different drive cycle can be calculated.

Section II explains about drive range and explain a process to use data points as timeseries object by which it can be used for real time simulation of vehicle. Section III explains about different force that acts on vehicle and in Section IV method to create a mathematical model using the equations representing the force is presented, at the end of this section force vs. time graph for different drive cycle is presented. Section V describes how this force can be used to calculate electric power and energy demand of the vehicle. Section VI concludes this paper.

II DRIVE CYCLE

A drive cycle is a series of data points representing the speed of a vehicle versus time [1].

Generally drive cycles are produced by the agencies of different countries those concern with emissions and fuel consumption of vehicle. Traditionally fuel consumption and emission tests are performed on chassis dynamometers emulating the drive cycle for the vehicle. Tailpipe emissions are collected and measured to indicate the performance of the vehicle. Drive cycles are very useful in vehicle simulations. Drive cycles are particularly useful in propulsion system simulations to predict performance of internal combustion engines, transmissions, electric drive systems, batteries, fuel cell systems, and similar components for electric vehicle. In this paper power demand of vehicle for following drive cycle is analyzed.

A. UDDS

UDDS is an abbreviation for Urban Dynamometer Driving Schedule and refers to a United States Environmental Protection Agency mandated dynamometer test on fuel economy that represents city driving conditions which is used for light duty vehicle testing.

It is also known as U.S. FTP-72 (Federal Test Procedure) cycle, LA-4 cycle, in Sweden as A10 or CVS (Constant Volume Sampler) cycle and in Australia as the ADR 27 (Australian Design Rules) cycle.

The cycle simulates an urban route of 7.5 mi (12.07 km) with frequent stops. The maximum speed is 56.7 mph (91.25 km/h) and the average speed is 19.6 mph (31.5 km/h). The cycle has two phases: a "cold start" phase of 505 seconds over a projected distance of 5.78 km at 41.2 km/h average speed, and a "transient phase" of 864 seconds, for a total duration of 1369 seconds (Shown in fig.1). [2]

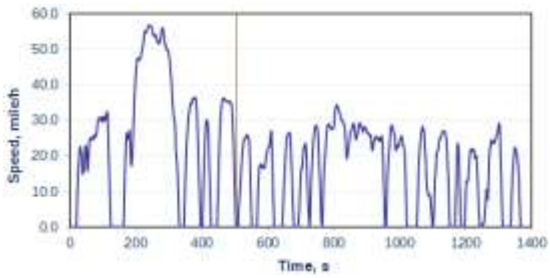

Fig.1 FTP-72 Drive Cycle

B. FTP-75

FTP-75 driving cycle of the EPA Federal Test Procedure is identical to the UDDS plus the first 505 seconds of an additional UDDS cycle. The procedure is updated by adding the "hot start" cycle in FTP-72 that repeats the "cold start" cycle of the beginning in UDDS.

EPA FTP-75 driving cycle simulates a city route of 11.04 mi (17.77 km) with frequent stops. The maximum speed is 56.7 mph (91.25 km/h) same as FTP-72 and the average speed is 21.2 mph (34.1 km/h). The cycle has 3 phases: a "cold start" phase of 505 seconds over a projected distance of 5.78 km at 41.2 km/h average speed, and a "transient phase" of 864 seconds, then a hot start phase same as cold start phase for a total duration of 1874 seconds (Shown in fig.3). [3]

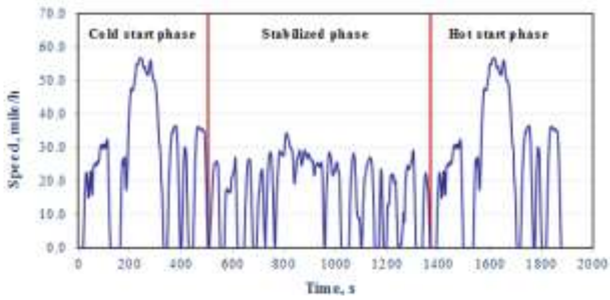

Fig.2 FTP-75 Drive Cycle

The average speed is different but the maximum speed remains the same as in the UDDS. Originally drive cycles are produced as a reference point for fossil fuelled vehicles. Single standard drive cycles provided fuel consumption and emission comparison data amongst different vehicles. Drive cycles like UDDS and FTP-75, are very useful to estimate the range in distance travelled by an electric vehicle in a single charge.

C. US06

The US06 Supplemental Federal Test Procedure (SFTP) was developed to address the shortcomings with the FTP-75 test cycle in the representation of aggressive, high speed and/or high acceleration driving behavior, rapid speed fluctuations, and driving behavior following startup.

SFTP US06 is a high speed/quick acceleration loop that lasts 10 minutes, covers 8 miles (13 km), averages 48 mph (77 km/h) and reaches a top speed of 80 mph (130 km/h). Four stops are included, and brisk acceleration maximizes at a rate of 8.46 mph (13.62 km/h) per second. The engine begins warm and air conditioning is not used. Ambient temperature varies between 68 °F (20 °C) to 86 °F (30 °C).

The cycle represents an 8.01 mile (12.8 km) route with an average speed of 48.4 miles/h (77.9 km/h), maximum speed 80.3 miles/h (129.2 km/h), and a duration of 596 seconds. (Shown in fig.3). [4]

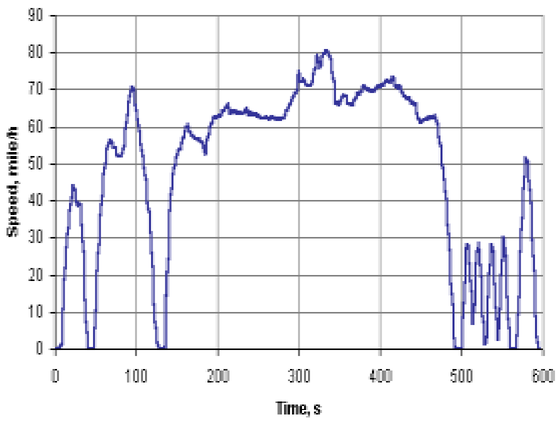

Fig.3 US06 Drive Cycle

D. SC03

The SC03 Supplemental Federal Test Procedure (SFTP) has been introduced to represent the engine load and emissions associated with the use of air conditioning units in vehicles certified over the FTP-75 test cycle.

SFTP SC03 is the air conditioning test, which raises ambient temperatures to 95 °F (35 °C), and puts the vehicle's climate control system to use. Lasting 9.9 minutes, the 3.6-mile (5.8 km) loop averages 22 mph (35 km/h) and maximizes at a rate of 54.8 mph (88.2 km/h). Five stops are included, idling occurs 19 percent of the time and acceleration of 5.1 mph/sec is achieved. Engine temperatures begin warm.

The cycle represents a 3.6 mile (5.8 km) route with an average speed of 21.6 miles/h (34.8 km/h), maximum speed 54.8 miles/h (88.2 km/h), and a duration of 596 seconds. (Shown in fig.4). [5]

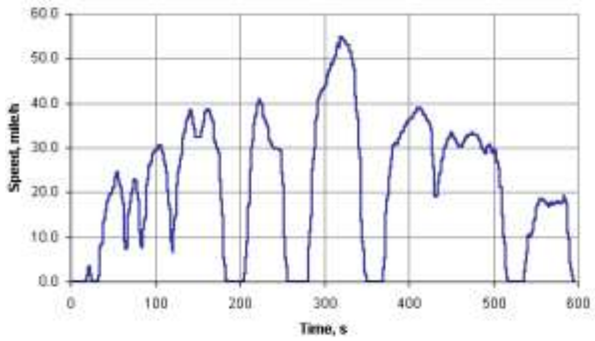

Fig.4 US06 Drive Cycle

III FORCES ACTING ON A VEHICLE

For any mission profile, an electric road vehicle is subjected to forces that the onboard propulsion system has to overcome in order to propel or retard the vehicle. These forces are composed of several components as illustrated in fig.5. The effort to overcome these forces by transmitting power via the vehicle drive wheels and tyres to the ground that propels the vehicle forward is known as thrust vector and a force equal and opposite to thrust vector, in this paper this force will be called the total tractive effort or total tractive force. [6]

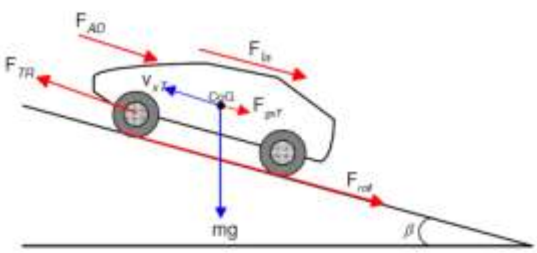

Fig.5 Longitudinal Force Acting on a Vehicle

Total tractive effort is the sum of all these forces

$$\mathbf{F_{te} = F_{la} + F_{hc} + F_{rr} + F_{ad}}$$

where

F_{la} is the linear acceleration force,

F_{hc} is the gravitational force acting on the vehicle on non-horizontal roads,

F_{rr} is the rolling resistance force,

F_{ad} is the aerodynamic drag force.

Linear Acceleration Force

The linear acceleration force is derived from Newton's second law of point mass motion and expressed as,

$$F_{la} = m\,(dV_{xT}/dx)\,(dt) = m\,a$$

Where "a" is the linear acceleration of the point mass "m" travelling. This force provides the linear acceleration to the vehicle. It is the most dominant component of force acting on a vehicle.

Hill climbing force

The hill climbing force depends on the slope angle of the road in respect to the horizon. This forced is induced by gravity when the vehicle travels on a non-horizontal plane. A climbing mission of the vehicle results in a positive force while a descending mission results in a negative force. This force is expressed as,

$$F_{hc} = mg \sin\Psi$$

Where the vehicle inclination angle Ψ is expressed in radians, m is the total vehicle mass and g is the acceleration due to gravity ($9.81 m/s^2$).

Rolling resistance force

F_{rr} is produced by the hysteresis of the tyres at the contact surface with the roadway. When the tyres rolls, the centroid of vertical forces on the wheels move forward from beneath the axle towards the direction of motion of the vehicle. The weight acting on the wheel and the road normal forces are misaligned and thus exert a retarding torque. This force opposes the rotation of the wheel and is expressed as,

$$F_{rr} = sgn[V_{xT}]\,(c\,m\,g)$$

where

F_{rr} = rolling resistance or rolling friction (N, lb_f)

c = rolling resistance coefficient - dimensionless (coefficient of rolling friction - CRF)

The rolling coefficients for pneumatic tyre on dry roads can be calculated as

$$c = 0.005 + 1/p\,(0.01 + 0.0095(v/100)^2)$$

where

- ***c*** = rolling coefficient
- ***p*** = tyre pressure (bar)
- ***v*** = velocity (km/h)

sgn[V_{xT}] is a the signum function of the vehicle tangential velocity(V_{xT}), and is given as,

$$sgn[V_{xT}] = \begin{cases} 1 & if\ V_{xT} > 0 \\ -1 & if\ V_{xT} < 0 \end{cases}$$

Aerodynamic drag

The aerodynamic drag force, F_{ad} acting on a vehicle is due to the viscous friction of the surrounding air acting on the vehicle surface and the pressure distribution induced by the downwash of trailing vortices behind the vehicle. The force opposes the motion of the vehicle and is influenced by the frontal area, shape and protrusions of the vehicle shell design. As there are multiple factors that contribute to this resistive force, it is commonly approximated using a prismatic vehicle body with a frontal area. The stagnation pressure caused by the product of the frontal area and ambient air density is multiplied by a constant drag coefficient. The total aerodynamic drag force is then expressed to include the vehicle and headwind velocity as,

$$\mathbf{F_{ad} = sgn[V_{xT}]\ (.5\ c_d\ \rho\ (V_{xT} + v_o)^2\ A)}$$

where

F_{ad} = drag force (N)

c_d = drag coefficient

ρ = density of fluid (1.2 kg/m3 for air at NTP)

V_{xT} = Vehicle tangential velocity

v_0 = head wind velocity

A = characteristic frontal area of the body

For accurate values of the aerodynamic drag c_d, the use of wind tunnels is required. Typical values of c_d for passenger vehicles ranges from 0.19 to 0.3 and 0.8 to 1.5 for larger vehicles such as busses and trucks.

IV MODELLING OF ELECTRIC VEHICLE

To model vehicle according to the mathematical equations described in Section III, drive cycle data is required as an input. Drive cycle data points are converted into time series object after following process.

- Importing text file to matlab
- Create timeseries object
- Save time series object in .mat file [ftp75= timeseries(y1,x1, 'name', 'ftp75')]
- Load and again save it version 7.3 [load('ftp75.mat')
  save('ftp75.mat', 'ftp75', '-v7.3')]

Model is simulated in Matlab/Simulink environment. Simulated matlab/simulink model provides the different forces acting on a vehicle and provides the total tractive effort required to force the vehicle forward according to input speed profile. For earlier mentioned drive cycles total tractive effort vs. time graph is shown from fig.6 to fig.9.

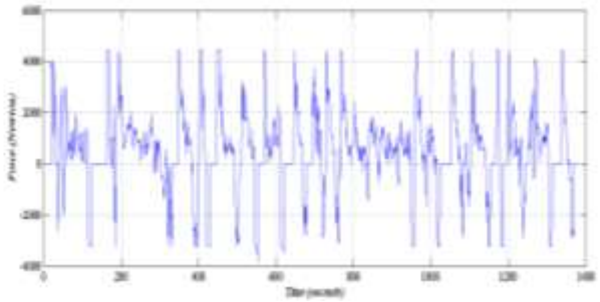

Fig.6 Force on a Vehicle when drive profile is FTP-72

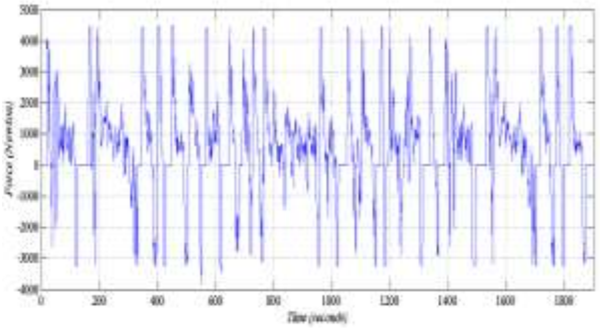

Fig.7 Force on a Vehicle when drive profile is FTP-75

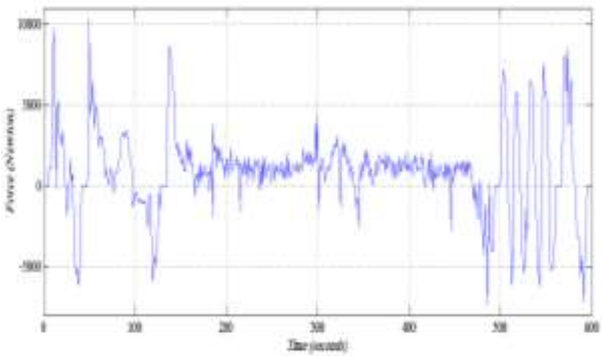

Fig. 8 Force on a Vehicle when drive profile is US06

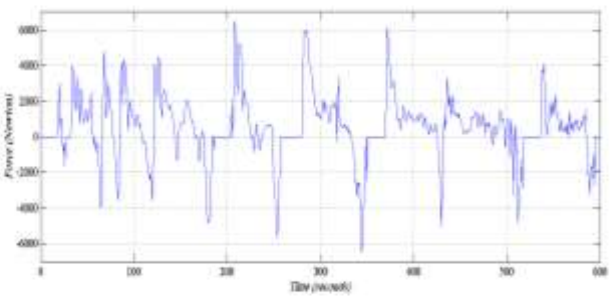

Fig. 9 Force on a Vehicle when drive profile is SC03

V POWER AND ENERGY REQIREMENT OF VEHICLE

Dimensioning of the onboard energy storage systems in an electric vehicle are based on both the instantaneous power demand as well as the energy demand. Design and sizing of an energy storage system to meet the propulsion demands for a given acceleration and steady state velocity profile is obtained from the energy requirement of the propulsion system. It suggests that drivability of electric vehicle depends on both power and energy delivering capability of electric vehicle’s energy storage system. Technically power and energy delivering capability of energy storage system is called power density and energy density of energy storage system. Energy storage system with better power density provides better response to the vehicle and energy storage system with better energy density provides better drive range.

From trust vector or total tractive force to calculate power and energy in watts/kilowatts and kilowatts hour proceeding according to the dimension analysis of newton, watts/kilowatts and kilowatts hour is useful. Dimension analysis suggests that which quantity in which units (meter per sec or kilometer per hour) mathematically operate with each other to obtain desired output. Dimensions of force, power and energy is expressed below:

$$\text{Force} \rightarrow \text{Newton} \rightarrow \text{Kg m/s}^2$$

$$\text{Power} \rightarrow \text{Watts} \rightarrow \text{Kg m}^2\text{/s}^3$$

$$\text{Energy} \rightarrow \text{Joule} \rightarrow \text{Kg m}^2\text{/s}^2$$

Analysis of dimension helps us to analyses that to calculate power, multiplication of force and velocity vector is required and to calculate energy power needs to be integrate over time range of drive cycle.

$$\text{Force (N)} \rightarrow \text{Power (W)} \rightarrow \text{Energy (J)} \rightarrow \text{Energy (Watt hour)}$$

According to the process explained above Simulink/matlab model is created and power and energy requirement of electric vehicle is calculated. Graphical representation of power consumption by vehicle for earlier mentioned drive cycle is shown from fig.10 to fig.13.

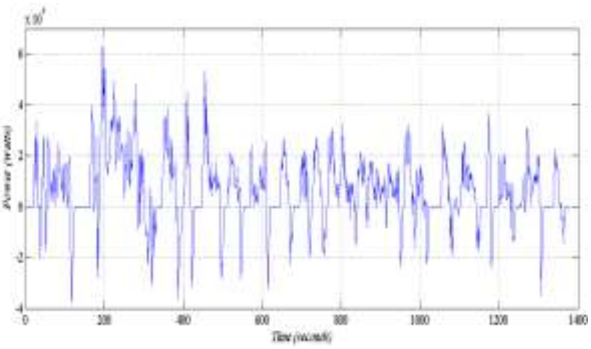

Fig.10 Power demand of a Vehicle when drive profile is FTP-72

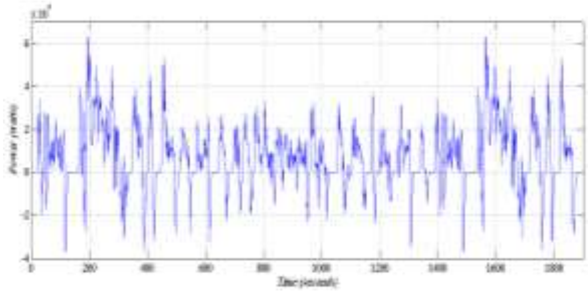

Fig.11 Power demand of a Vehicle when drive profile is FTP-72

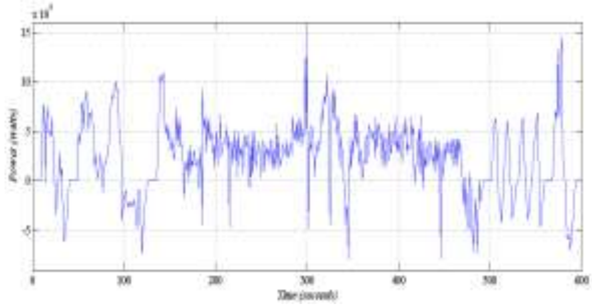

Fig.12 Power demand of a Vehicle when drive profile is US06

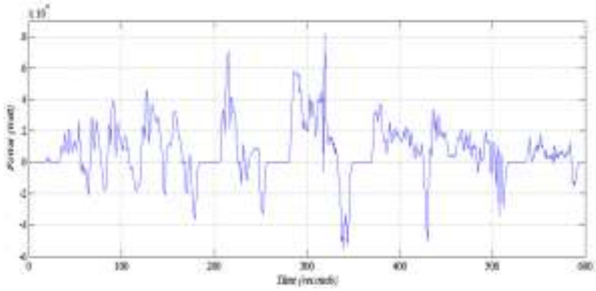

Fig.13 Power demand of a Vehicle when drive profile is SC03

Analysis of power vs. time curve helps to conclude that when vehicle is simulated with:

- FTP-72 drive cycle maximum power demand of vehicle is 17.77kW while maximum power available during regenerative braking is 7.6kW. Average power demand for vehicle with driving profile according to FTP-72 is 2.7kW.
- FTP-75 drive cycle its maximum power demand and maximum regenerative power is same as obtained in FTP-72 while average power demand slightly increased to 2.96kW.
- US06 drive cycle maximum power demand of vehicle is 39.78kW and maximum power available during regenerative braking is 17.23kW. For the total drive profile average power demand is 7.55kW.
- SC03 drive profile average power demand is 3.008kW while maximum power demand and maximum regenerative power available is 23.08kW and 11.92kW.

Energy required vehicle has no particular significance till energy storage system is unknown as round trip efficiency of regenerative power will be different for different storage system. For ultracapacitor round trip efficiency ranges between 85-95% while for lithium ion battery round trip efficiency of regenerative power is

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50-60%.[7] Considering lithium ion battery as energy storage employing in electric vehicle and considering 50% round trip efficiency simulation result showing energy consumption with time for different drive cycle is shown from fig.14 to fig.17.

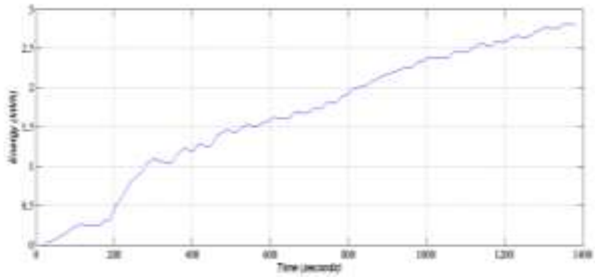

Fig.14 Energy Consumes by a Vehicle when drive profile is FTP-72

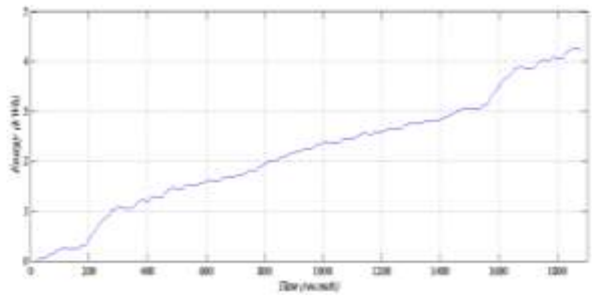

Fig.15 Energy Consumes by a Vehicle when drive profile is FTP-75

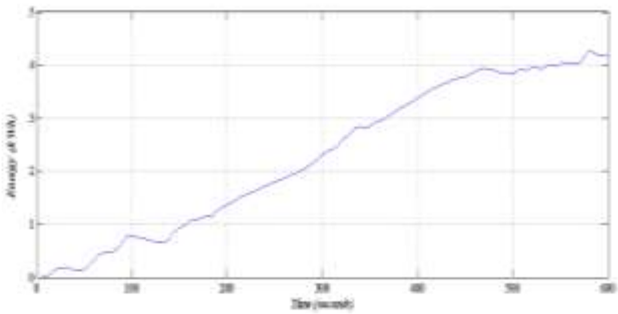

Fig. 16 Energy Consumes by a Vehicle when drive profile is US06

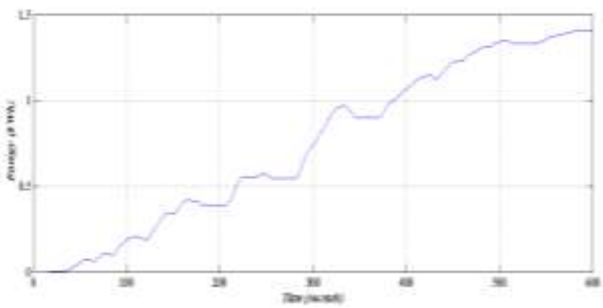

Fig. 17 Energy Consumes by a Vehicle when drive profile is SC03

VI CONCLUSION

In this paper a method to simulate an electric vehicle by utilizing mathematically equations based on newton's law of motion is presented. Industry standard drive cycles are uses for simulation. Simulation according to FTP-72, FTP-75, US06 and SC03 is performed and maximum electric power demand (kW) is calculated.

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