Design, Modelling and Analysing of a Vehicle Drivetrain using SimDriveline

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ABSTRACT

In the vehicle industry, it is required to model a Vehicle Drivetrain based on a well-recognized system, and analyze the system behavior with the aim to redesign or modify the system to meet different operational requirements. So, this paper aimed to Design, Modelling and Analyzing of a Vehicle Drivetrain using SimDriveline. The followed methodology was divided into four steps, which are; Analysis of Variable and Simple Gear Systems, Analysis of Simple Hydraulic Clutch System, Modelling and Investigation of a Vehicle Drivetrain, as well as Model based design of a simple power transmission system using SimDriveline. The results of this paper showed that in the simple gear that with introducing one of the meshing there was a slightly decreases in velocity and the torque was unstable and not smooth. In the variable gear the velocity has considerably decreased where in the torque was increased. Also, in the clutch the pressure has increased after modifying the input signal and the engine power in earlier time. The change was very small after changing the simple gear with variable gear in the drivetrain vehicle model which cannot be taken into consideration however, when the physical constant block has replaced by throttle there was a big effect on the engine power as well as the vehicle speed.

Key Words: Vehicle Drivetrain, SimDriveline, Simple Hydraulic Clutch, Variable Gear Systems, Simple Gear Systems

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INTRODUCTION

In general, various components of machine system such as; belt drives, clutch and gear systems but lack experience in design, modelling and analysis of this kind of system, for example, a Vehicle Drivetrain. This paper is designed in such a way that you will first be familiar with simple system by exploring and analyzing available examples, then moving on to define input into the system to investigate the output or the behavior of the system. In addition, it is required to model a Vehicle Drivetrain based on a well-recognized system, and analyze the system behavior with the aim to redesign or modify the system to meet different operational requirements.

Aims and Objectives

This paper aims to Design, Modelling and Analyzing of a Vehicle Drivetrain using SimDriveline. So, there are many objectives that will be applied to reach paper aims, which are:

- To model clutch and gear systems as power transmission circuits in addition to vehicle drivetrain using SimDriveline,
- To analyze the behavior of system by comparing the input signals from signal with the output signals,
- To be able to perform model based design (simple power transmission system).

Methodology

As previously mentioned, this paper aims to Design, Modelling and Analyzing of a Vehicle Drivetrain using SimDriveline. The followed methodology in this paper is divided into main four steps, as follows:

- Analysis of Variable and Simple Gear Systems,
- Analysis of Simple Hydraulic Clutch System,
- Modelling and Investigation of a Vehicle Drivetrain,
- Model based design of a simple power transmission system using SimDriveline.

Results and Discussion

In order to achieve the aim of this paper, Variable and Simple Gear Systems are analyzed as a first step:

Analysis of Variable and Simple Gear Systems

Simple gear unit

Figure 1 includes block diagram of simple gear unit system, which is compose of several componants to do specified function. Solver is a Numerical method employed in solving the model ordinary differential equation, where the user solved the initial value problem and fulfilled the requirements of the accuracy.

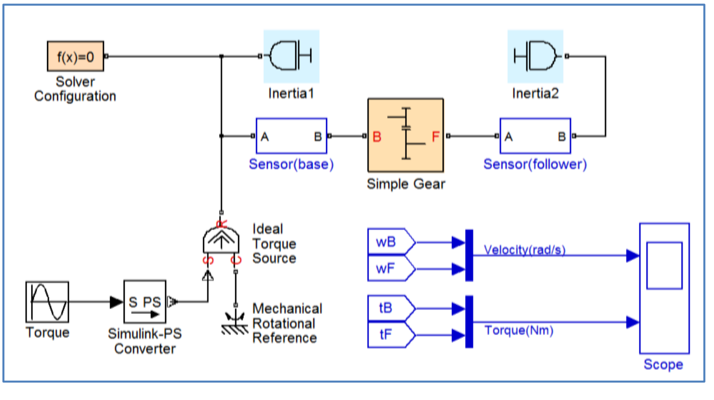


Figure 1: Simple Gear Unit

The physical network requires the setting data of the solver to perform the simulation. The solver parameters are determined via solver configuration block. These parameters are essential for simulation and the block characterizes with single conserving port. Also, Figure 1 shows Simulink-PS Converte that is used in converting the input signal into physical signal. Simulink sources are linked through this block to the inputs of Physical Network diagram. Each input might be used as a filter or to enter the derivatives into further signal ports. The filtering process of the input produces the rime derivative, while first order filter produces a single derivative. Filter of second order produces second and first derivatives.

Also, Mechanical Rotational Reference that represents the reference point and it is employed for each mechanical rotational block. Furthermore, each port that is linked to ground rigidly should be connected to this reference. The block possess each single mechanical rotational port. In addition to PS-Simulink Converter that is employed in converting the physical signal to output signal. The outputs of Physical Network diagram are linked to Simulink scopes via this block or any other Simulink block. The output signal module must characterizes with unit expression, which is similar to the physical signal units. Figure 1 also shows scope that is used to show the output signals created by the system. These signals are generated throughout the simulation when input signals are given to the system. Finally, Inertia is used to represent the ideal mechanical rotational inertia and it is characterizes with single mechanical rotational conserving port. The block positive direction starts from the port and ends with the reference point. In case that the acceleration of the inertia is within positive direction, the torque of inertia is then positive and it is represented by equation below;

$$T = J\frac{d\omega}{dt}$$

Where that ω- is Angular velocity, T- is Inertia torque, t- is Time, and J- is Inertia.

Simulink signals differ from PS since the nature of Simulink signals is mathematical, while the PS nature is physical. The S-PS in the SimDriveline stands for the Simulink signal, while the PS-S stands for the physical signal.

PS-Simulink converter

- The needed units for the output signal are specified by its parameters. The units of the output signal should be the same as the signal input units. Simulink output signal is unit-less, but if an output unit is specified, the Simulink signal output is expressed in the required units with the block gain help that is similar to the factor of conversion.
- The reading on the display does not modify if the block of PS-Simulink Converter is fixed after the block of PS Gain. The unit parameter determined for the output signal in the block of PS-Simulink Converter does not affect the display.

Simulink-PS converter

- The needed units are specified by the unit parameter of the Input signal and its value is determined to be one in case that the block does not have specified unit. Destination block is used in determining the units of the physical signal when this occurs. The meter-kilogram-second (MKS) system is employed as the destination block default units. If another units' set is specified, these units are sent by the unit manager to the Simulink. Differently, the unit conversion takes place in case that the signal is given to the destination block.

- Fixing the block of PS Gain after the block of Simulink PS Converter prevent the spreading of the unit to the whole physical network and a torque of 1000Nm is created by the Source of Ideal Torque. This torque does not depend on the unit parameter of the Input signal that is determined within the block of Simulink PS Converter.

Type of sensors used in this model

There are two types of sensors have been used in this mode, which are; Motion and Torque sensor as shown in Figures 2 and 3. The ideal motion sensor is represented by the block of the Ideal Rotational Motion Sensor. Motion sensor converts the quantities that are transferred between mechanical rotational nodes. These quantities are converted to a control signal that depends on the angular velocity or angle. Inertia, energy consumption, friction and delays are not considered by the ideal sensor.

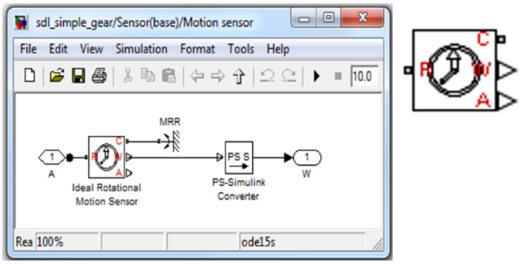


Figure 2: Ideal Rotational Motion Sensor

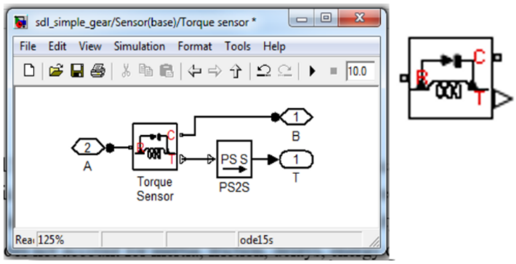


Figure 3: Shows Torque Sensor

The block of the Ideal Torque Sensor is employed for a device that can modify a variable detected via the sensor into a signal that depends on the generated torque. Again, Inertia, energy consumption, friction and delays are not considered by this sensor.

The output signals of simple gear unit on the scope

Via double click on the simple gear, the figure below is obtained. Click then on "meshing losses "and selecting "no meshing losses-suitable for HIL simulation" to be compared with meshing changing. The simulation is then started by clicking the button "run" as illustrated below in figure 4. Via double click on "Scope", the simulation window for torque and velocity output are as given below in the following figure.

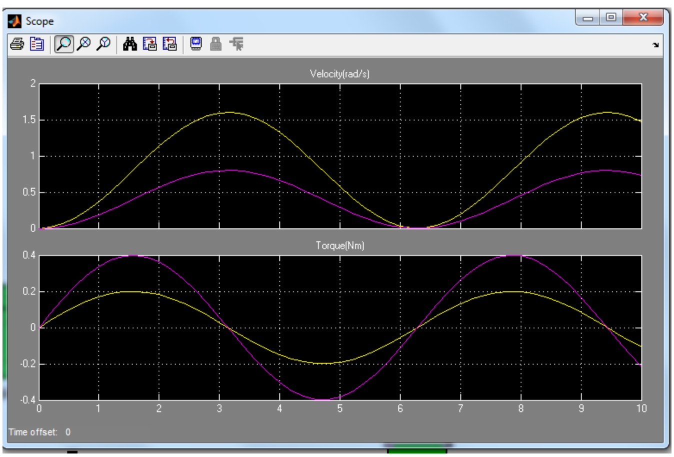


Figure 4: velocity and torque on Simulation Window

The meshing losses to the gear and the output signals on the scope

Different meshing for the parameters of the gear were then considered, which are efficiency constant =0.8 and angular velocity threshold=0.01 rad/s.

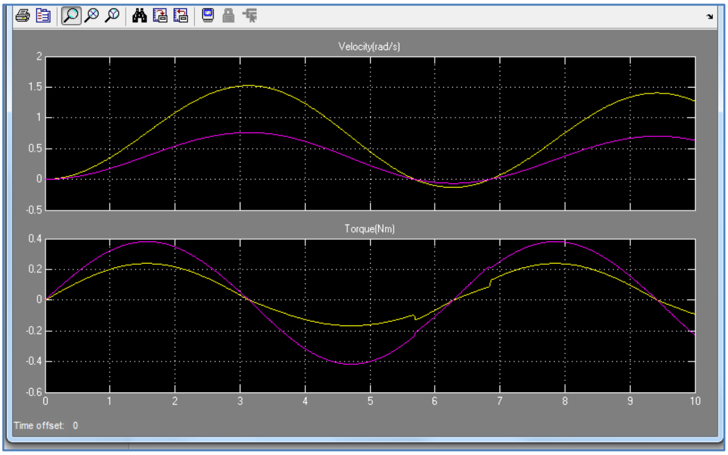


Figure 5: Simulation for Constant Efficiency

As illustrated in Figure 5, the angular velocity decreases from 1.6 to 1.524. It has been noticed from looking at figures 8 and 10 that there is a decrease in velocity from 1.6 to 1.524. In addition, the velocity goes below zero in move line unlike the yellow one, which does not exceed zero. It is also noticed that the torque is not smooth and stable with the selected efficiency constant not the same as without any losses in move line.

Variable Gear

The block diagram for the variable gear is illustrated Figure 6. Where Variable Ratio Transmission block is A gearbox of variable ratio type is represented via Variable Ratio Transmission. Electric or hydraulic transmission and mechanical belt CVTs are employed for transferring torque between the driveshaft axes, follower and base and that are connected together. The ratio between the input and the output velocities of the angular shaft are given by the input of the physical signal “r”.

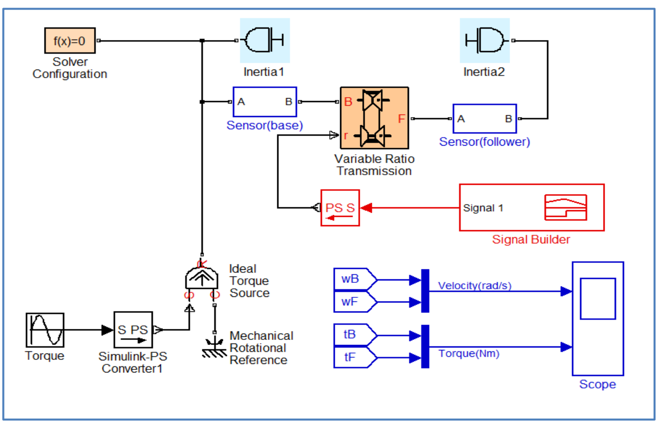


Figure 6: Variable Gear

The mechanical rotational conserving ports are described using the connections F (follower) and B (base). The parameters for the output shaft rotation determine the link between the directions rotation directions of the follower and the base. A variable gear ratio is determined for the driveshaft to rotate together and the rotation is chosen based on the base axis.

The block of the Signal Builder permits you do modifying the input of piecewise linear signal sources to be used later within the model. As shown in Figure 7, the signal builder input and the output signal are depicted in Figure 8 from the scope.

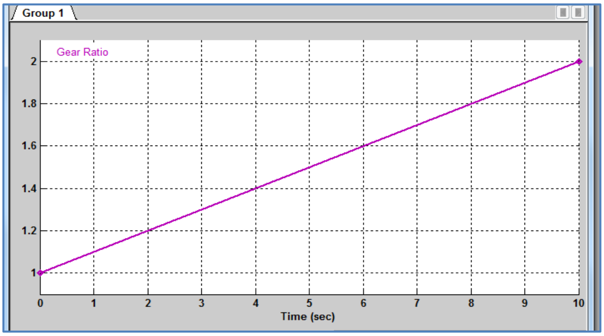


Figure 7: Signal Builder Input

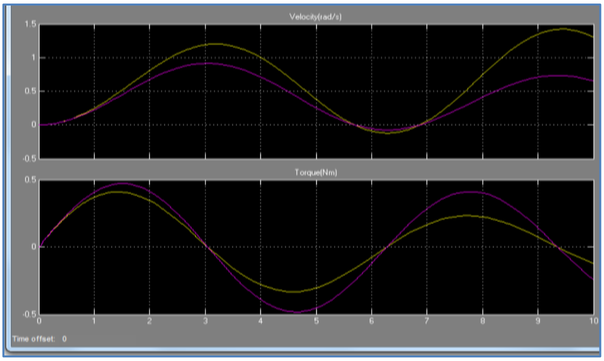


Figure 8: The Scope Output

A "unit step" signal was then added and it has been modified to the new signal as illustrated in Figures 9 and 10.

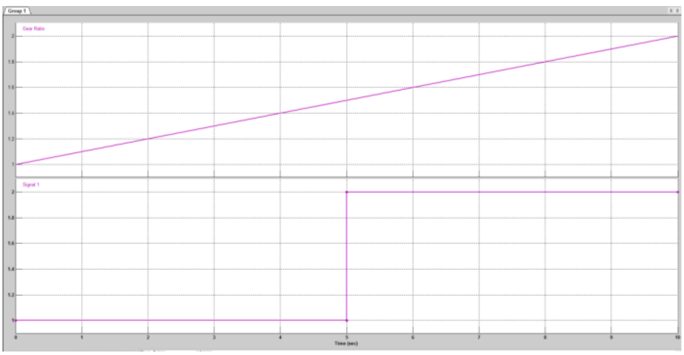


Figure 9: Adding unit step signal

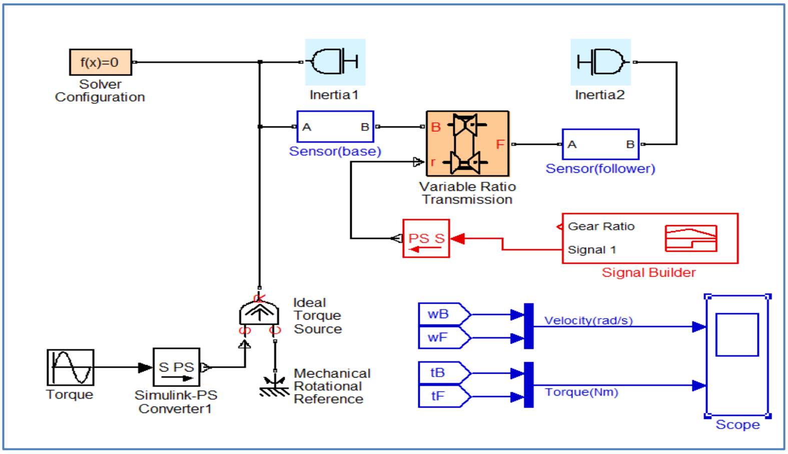


Figure 10: the connection to the new signal

The plot of the generated output signal, after adding the unit step signal, is illustrated below in the following figure. Compared to Figure 1, it can be noticed that there is a fall within the angular velocity from 1.2 to 1, while the torque increased from 0.471 to 2.3 since the higher gear is included. Figure 11 illustrates that the signals are varying continuously.

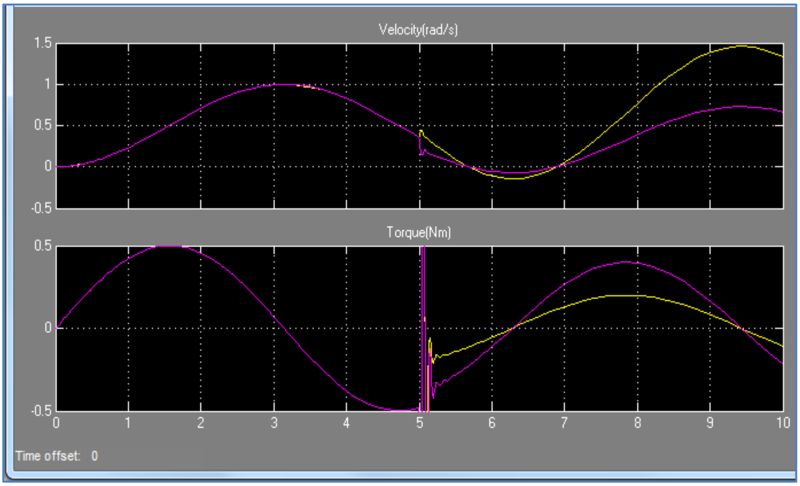


Figure 11: The new signal Output

Analysis of Simple Hydraulic Clutch System

Clutch system is an essential part of the vehicles and it permits the driver to put the vehicle in gear, it also shifts the gear when it begins moving. There are two available types of clutch systems, which are; Hydraulic clutch system and Mechanical clutch system. Hydraulic clutch disengages or engages the engine from the transmission as shown in Figure 12. A brake fluid is employed to operate the clutch, while the engine's crankshaft is employed in converting the rotational energy to helpful motion. When pressing the pedal of the clutch, the fluid is pressurized within the system. The pressure is transmitted later to the method of clutch plate. This results in disengaging the transmission from the engine. The Clutch Flywheel and disc are the parts that are often found within the hydraulic clutch system.

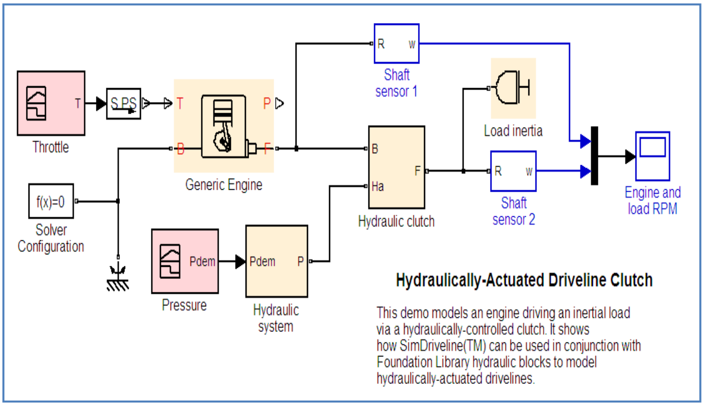


Figure 12: Hydraulic clutch model

The components of the hydraulic system are; Pressure Demodulator that is used to produce the input port for external input or the subsystem. Port blocks are used to connect the external environment and the system. Simulink-PS converter, which is used to produce physical signal. Also, Hydraulic Pressure Source block that is used to represent an ideal hydraulic energy source. It preserves the pressure at the outlet and it is not affected by the consumption rate of the system. The hydraulic outlet and inlet ports are symbolized via the block connections P and T and. control signal port is represented by the connection S. The block of Constant Area Hydraulic Orifice is used to provide a constant area orifice and it distinguishes between turbulent flow and laminar via considering the critical value of the flow rate and the Reynolds number through the orifice based on the differential pressure that across the orifice. In addition, Constant Volume Hydraulic Chamber is used to represent a chamber with a fixed volume. It is used in hydraulic valves, hoses, manifolds, pipes, pumps, and other different components. Finally, Connection Port block that is used to transfer the physical signal and the conserving connections. The transfer is performed to the subsystem block outer limit.

But, the components of hydraulic clutch are; Physical Modelling Connection Port block that is used to represent the subsystems. Hydraulic Pressure Sensor, which is used to represent the ideal hydraulic pressure sensor. This sensor converts the hydraulic pressure differential to a control signal that depends on this differential pressure. Also, Hydraulic Reference block that is used to represent the connection to the atmosphere pressure, in addition to Friction clutch that is used to transfer the torque between two driveline axes that uses friction in coupling them.

The pressure input and the throttle input are plotted as shown in Figures 13, 14, and 15.

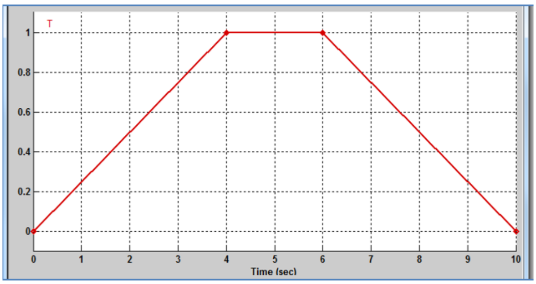


Figure 13: The throttle input

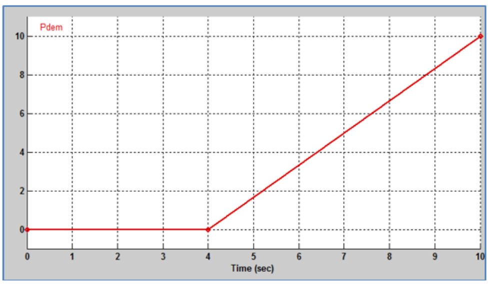


Figure 14: The pressure input

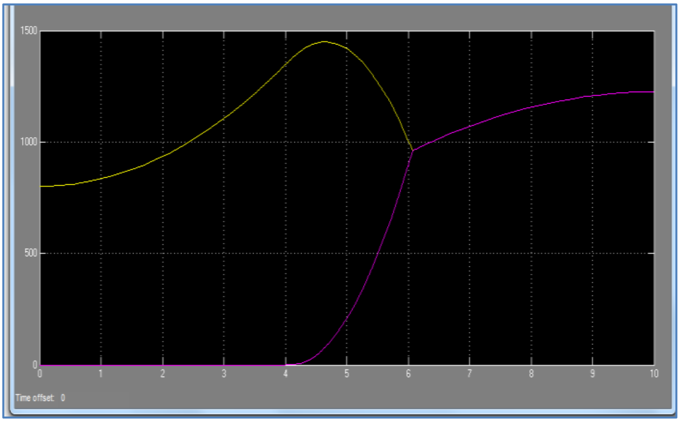


Figure 15: Output of the load RPM and Engine

The input is modified in this step to examine its effect on the output and the results are shown in Figures 16, 17, and 18.

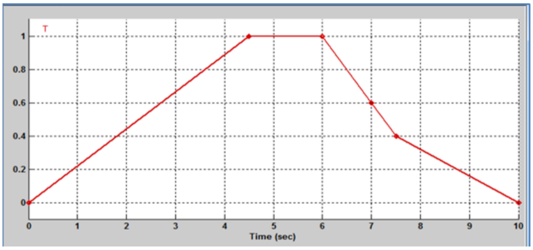


Figure 21: Input of throttle after modification

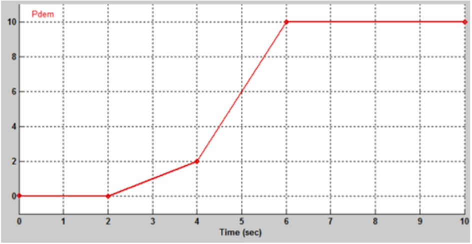


Figure 2: Input of Pressure after modification

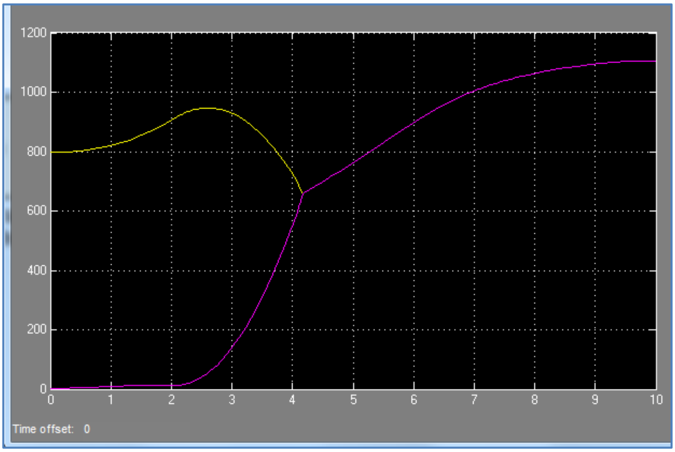


Figure 23: Signal after modifying the pressure and throttle input

As it is illustrated in figure 23, the pressure has started from 0 and stays constant until 4 then started increasing to reach 1224.75. The throttle in turns started from 800 and raised to reach1449 then start to decrease. In figure 26, the pressure started from 0 and reserved gradually increasing to reach 1106.24, also the throttle started from 800 and reached its peak value = 950 and then starts decreasing.

Modelling and Investigation of a Vehicle Drivetrain

The vehicle drivetrain model was built via SimDriveline as it illustrated in Figure 19. After the model is being created, the simulation running failed and the engine parameters were modified accordingly from no inertia to the inertia shaft to be 5kg*m^2 and the other inertia is set to be 1 kg*m^2. The initial velocity is set to be equal to zero; because that the vehicle start from the rest. The torque is divided two wheels within the rear axle using differential block. Since it is an open throttle test, constant block should be employed in order to set the throttle to be a 100%.

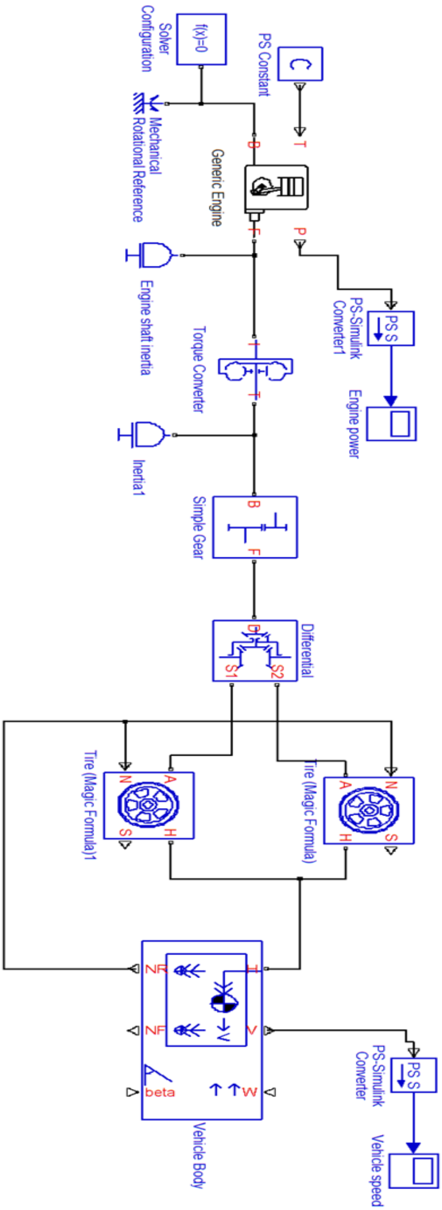


Figure 3: The Model of Vehicle Drivetrain

In this model, the purpose of Torque convertor is to couple two driveline axes. The viscous fluid in turns transfers the angular motion and torque, but the axes cannot be locked together. This converter performs between ports T and I and the block accounts for the angular velocities located between the driveline axes that are linked with each other. The ports of mechanical rotational conserving are symbolized via the connections T (turbine) and I (impeller). The torque flow is positive in case that it is engaged from port I to port T. The differential block is employed to couple the rotational motion along the later axes to rotational motion along the longitudinal. The clutches employed within the differentials in drivelines could be managed and controlled. These clutches connect the two output shafts, the control is performed via connecting the Differential block to the block of Controllable Friction Clutch.

The engine power and vehicle speed are plotted as shown in Figures 20 and 22.

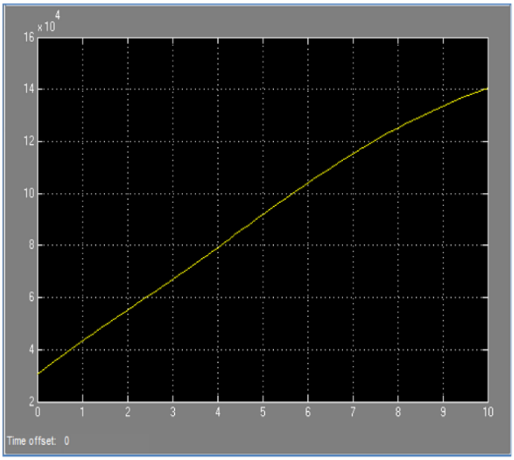


Figure 28: The power of the Engine

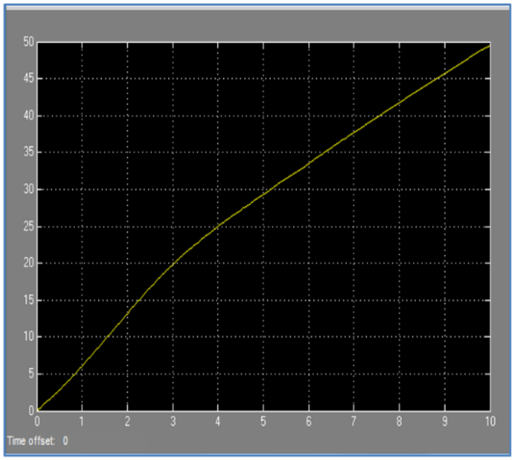


Figure 29: The speed of the Vehicle

In the first model, the power of the engine starts from 3*10^4 as it is illustrated in figure 28, it then increases to 14*10^4. On the other hand, the speed of the vehicle starts from 0 and reserved on increasing to approximately 50.

Then, a variable gear (variable ration transmission) is used instead of the simple gear in order to determine the gear changes with a Simulink-PS Converter and the signal builder and a (e.g. in the variable gear model), as well as to Plot the behavior of the relevant system output and system input signals, as illustrated in Figure 32.

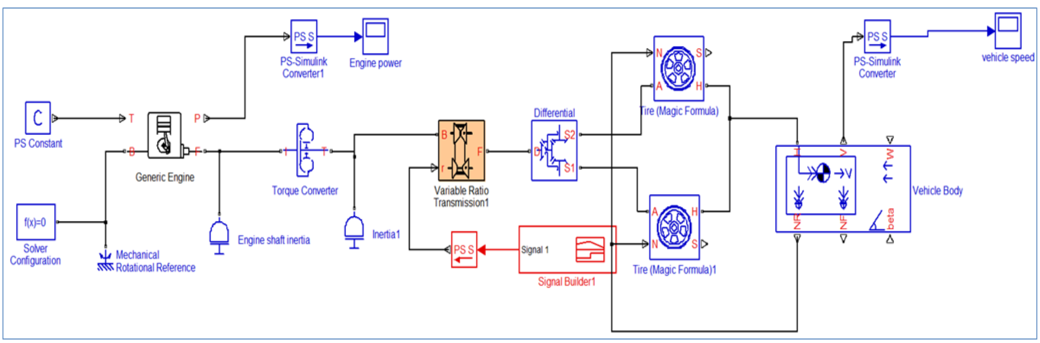


Figure 4: Modifying the simple gear with variable ratio transmission

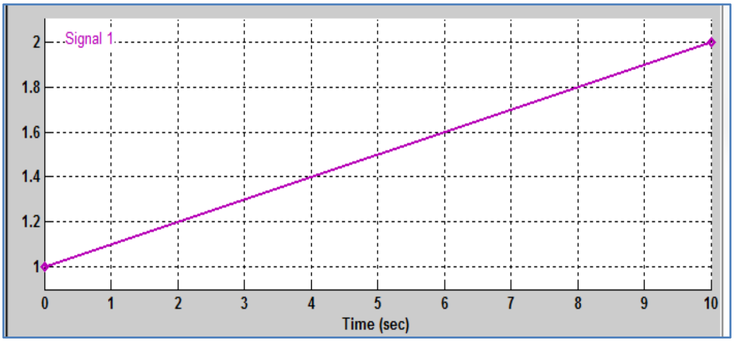
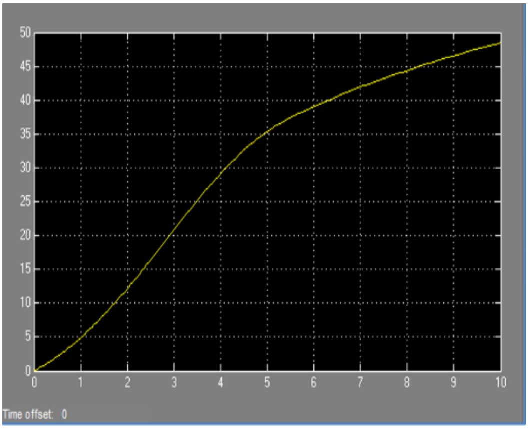


Figure 5: The signal builder Input



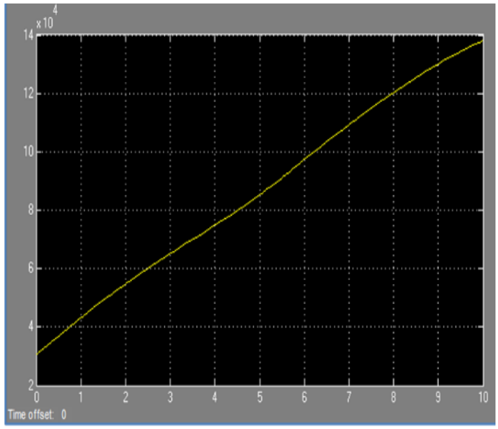


Figure 6: The speed of the Vehicle

Figure 7: The speed of the Engine

According to figure 31 and 32, it is clear that there is no large different in the signals, the speed of the vehicle speed increased fast from the zero as shown in figure 31. Rather than driven using Constant Physical Signal (Open Throttle), simulate a driving behavior where the power is gradually increased by the driver, it then stays constant for a small interval and decrease at similar rate to power increasing rate. The behavior of the relevant system input signal and system are plotted.

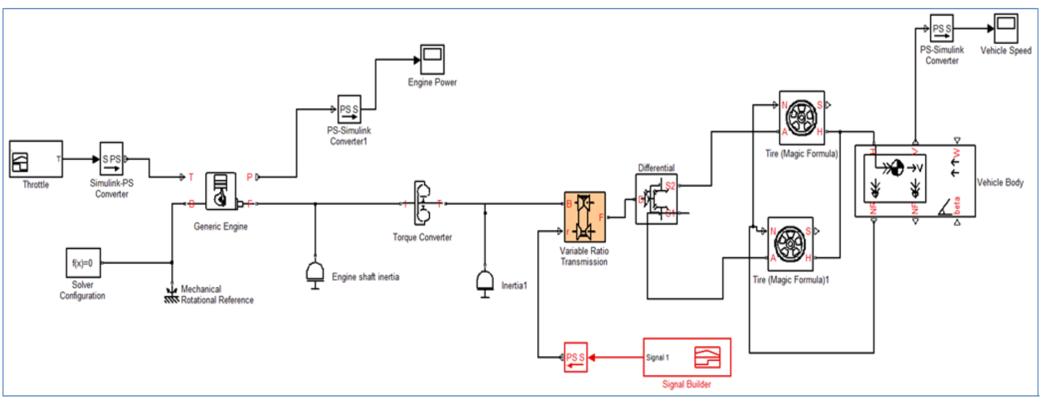


Figure 8: The Throttle was added to the model rather than constant physical signal

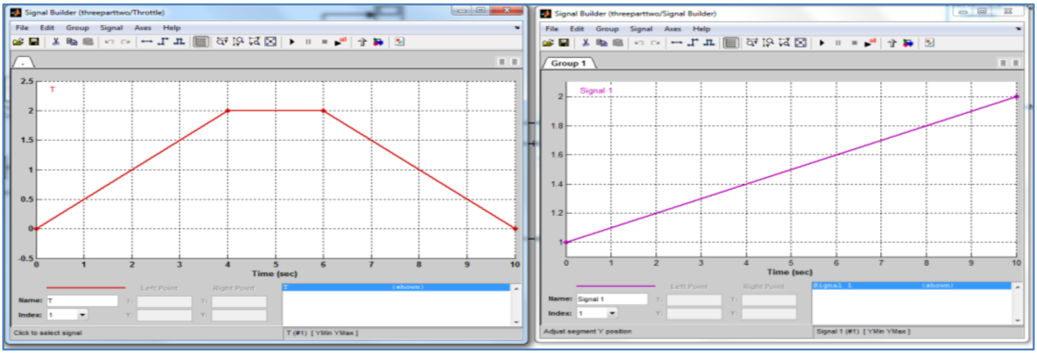


Figure 9: The throttle and signal builder Input

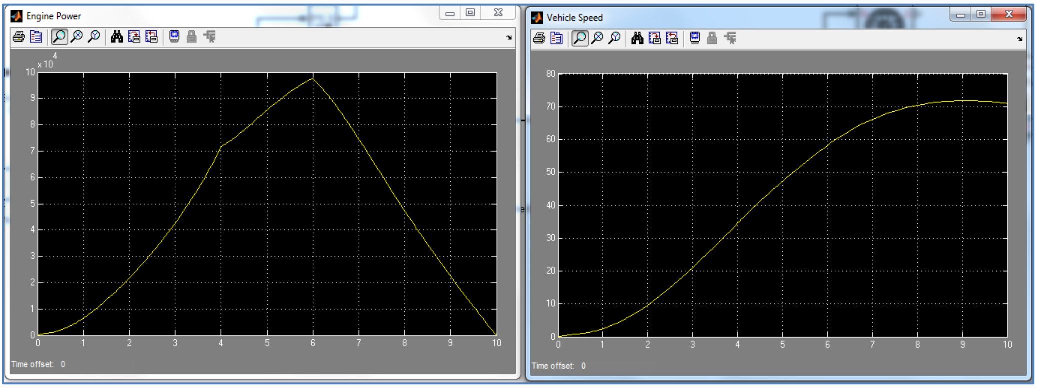


Figure 10: The Output of the Engine Power and Vehicle Speed

As it is illustrated in figure 35, the speed of the vehicle increased from 50 to 71.

Model based design of a simple power transmission system

A new design for simple power transmission system is built based on required calculations for total load, angular velocity, gear ratio, The entire inertia, The torque desired from a motor, The Load angular acceleration, the torque desired to overcome the load friction, as well as the power.

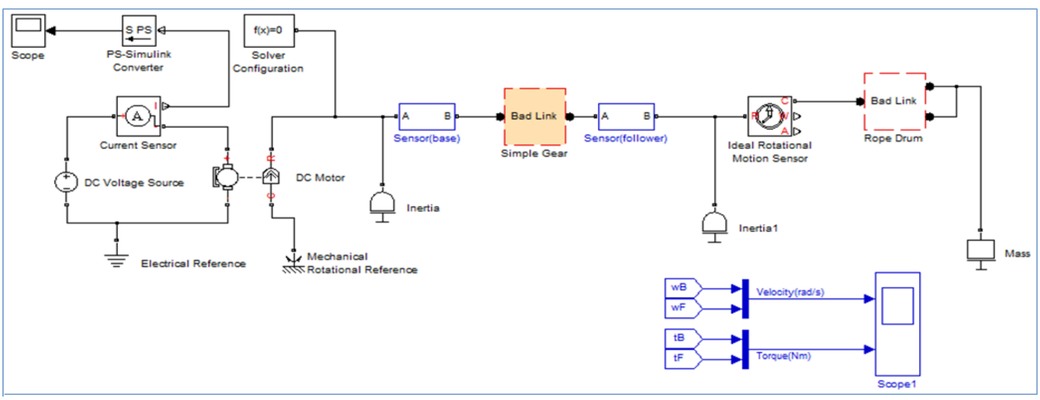


Figure 37: new design of power transmission system for lifting

$$Load\ mass\ (m)\ = 400kg:$$

$$Drum\ = 0.4m$$

$$Constant\ speed\ =\ 0.6\ m/s$$

$$The\ max\ motor\ speed\ =\ 30\ rev/s.$$

Total load is given by;

$$T_l = (400 \times 9.81) \times 0.2 = 784.8\ Nm$$

The Angular velocity is given by;

$$\omega = \frac{v}{r} = \frac{0.6}{0.2}$$

$$= 3\frac{rad}{s} = 3/2\pi \text{ rev/s}$$

The Gear ratio is given by;

$$n = \frac{maximum\ speed}{angular\ velocity} = \frac{30}{3/2\pi} = 62.8$$

The entire inertia at the motor is given by;

$$I_{total} = I_m + I_d + I_L$$

$$0.014 + 0.023 + 0.018 = 0.055\ kgm^2$$

The angular acceleration is given by;

$$a_m = \frac{maximum\ speed}{time}$$

$$= \frac{(30 \times 2\pi)}{1}$$

$$= 188.5\frac{rad}{s^2}$$

The torque desired from a motor is given by:

$$T_m = \frac{T_L}{n} + I_m . a_m$$

$$T_m = \frac{784.8}{62.8} + 0.055 \times 188.5$$

$$= 22.86\ Nm$$

The Load angular acceleration is given by;

$$a_L = \frac{a_m}{n} = \frac{188.5}{62.8}$$

$$= 3.00\ \frac{rad}{s^2}$$

The torque desired to overcome the load friction is given by;

$$T_f = T_L - I_L \times a_L$$

$$T_f = 784.8 - (0.018 \times 3.00)$$

$$= 784.75\ Nm$$

The power is given by;

$$P = \left(T_f \times w\right) + (I_L \times a_m \times \omega)$$

$$P = (784.75 \times 3) + (0.018 \times 188.5 \times 3)$$

$$= 2364.417\ w = 2.3\ KW$$

Suggest a suitable final torque desired by the motor

The desired accelerating torque is given by;

$$T_L = I_{Total} \times a_m$$

$$= 0.055 \times 188.5$$

$$= 10.36\ Nm$$

$$T_{max} = T_m + T_a$$

$$= 22.86 + 10.36$$

$$= 33.22\ Nm$$

Conclusion

There are different type of components that can be modelled using SimDriveline such as; Gears, Clutch models, Vehicle component models, Models of translational elements, Ideal and non-ideal model variants, enabling adjustment of model fidelity as well as Simscape language to extend component. Real time simulations can be generated on the basis of the SimDriveline models and then it can be converted into C language and the HIL tests can be performed. Abstract behavioural models are used for the configuration of the SimDriveline and the Simscape local solvers can make the simulation quicker with the help of a fixed step solver for the physical system and a separate solver can be used for the remaining model.

This paper has been achieved successfully with understanding how to build a model by using SimDriveline. It has been noticed in the simple gear that with introducing one of the meshing there was a slightly decreases in velocity and the torque was unstable and not smooth. In the variable gear the velocity has considerably decreased where in the torque was increased. Also, in the clutch the pressure has increased after modifying the input signal and the engine power in earlier time.

The change was very small after changine the simple gear with verable gear in the drivetrain vehicle model which cannot be taken into consideration however, when the physical constant block has replaced by throttle there was a big effect on the engine power as well as the vehicle speed. The calculation has been worked out as well as the suitable final torque also, simple power transmission system was built.

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