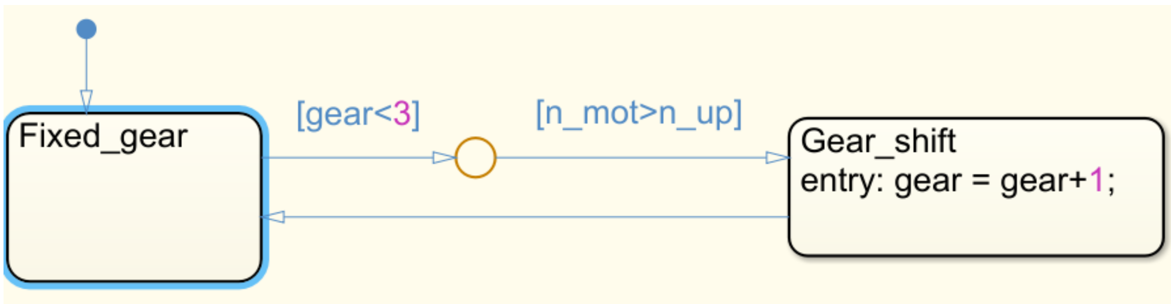
Longitudinal dynamics - Simulink model

Even if the physics behind the longitudinal dynamic is not so computational demanding, considering every possible influence over the vehicle could imply a certian degree of complexity. In this exercise a very attending model over the longitudinal dynamics is analysed.

Firstly the vehicle adopt the same EM as the previous exercise, however here a gear shifting logic is implemented with a *logic block*. However the control is very primitive, since it chages gear for $rpm > 9000$.



Furthermore, this model implement Pacejka tyre-ground model in addition to a radial tyre deformation. The vehicle dynamics is a direct application of the formula seen in the previous exercise.

What it requested from this exercise is to develop the Driveline block, consinsting on the driving wheels and differential. From the script provided it is possible to select the traction system prefered from the input menu.

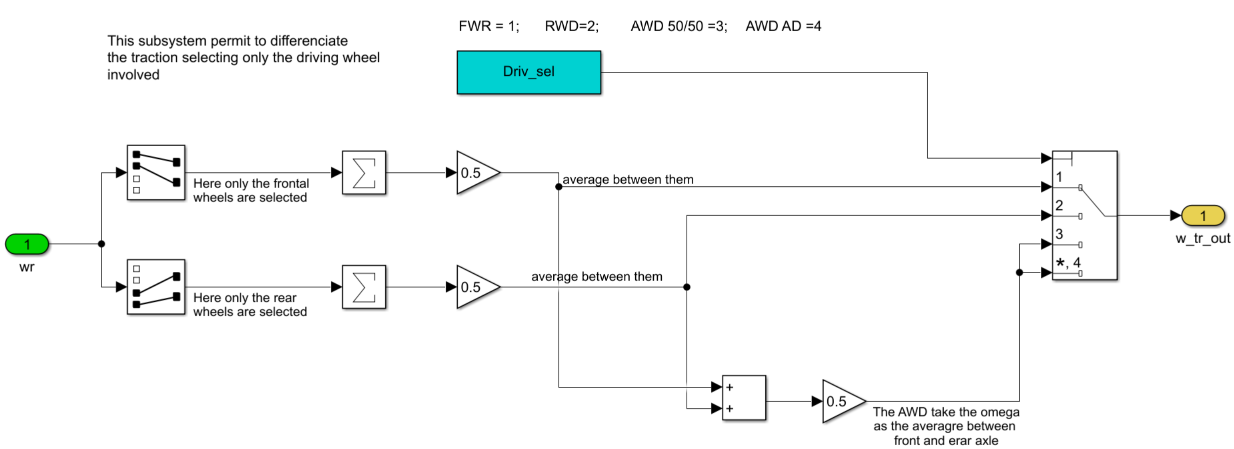
```
tract_str = {'FWD','RWD','AWD 50/50','AWD Active Diff'};
```

There are two blocks: one for the speed and one for the torque slitting among the wheels. They will be both developed here.

Speed block

Considering a very simple differential, the rotational velocity coming from the engine (or better from the gearbox) is equally splitted among each side of the vehicle:

$\omega_m = \omega_{d,in}\tau_i$ and then $\omega_{d,in} = \dfrac{\omega_L + \omega_R}{2}$. Initially the rotational speed has to be divided between the two axles, then on each side of the vehicle. The Simlunk model proposed is as follows:



Which means that depending on the traction selected a certain axle will be *"nullified"*, or in case of the AWD is splitted equally between front and rear.

Torque block

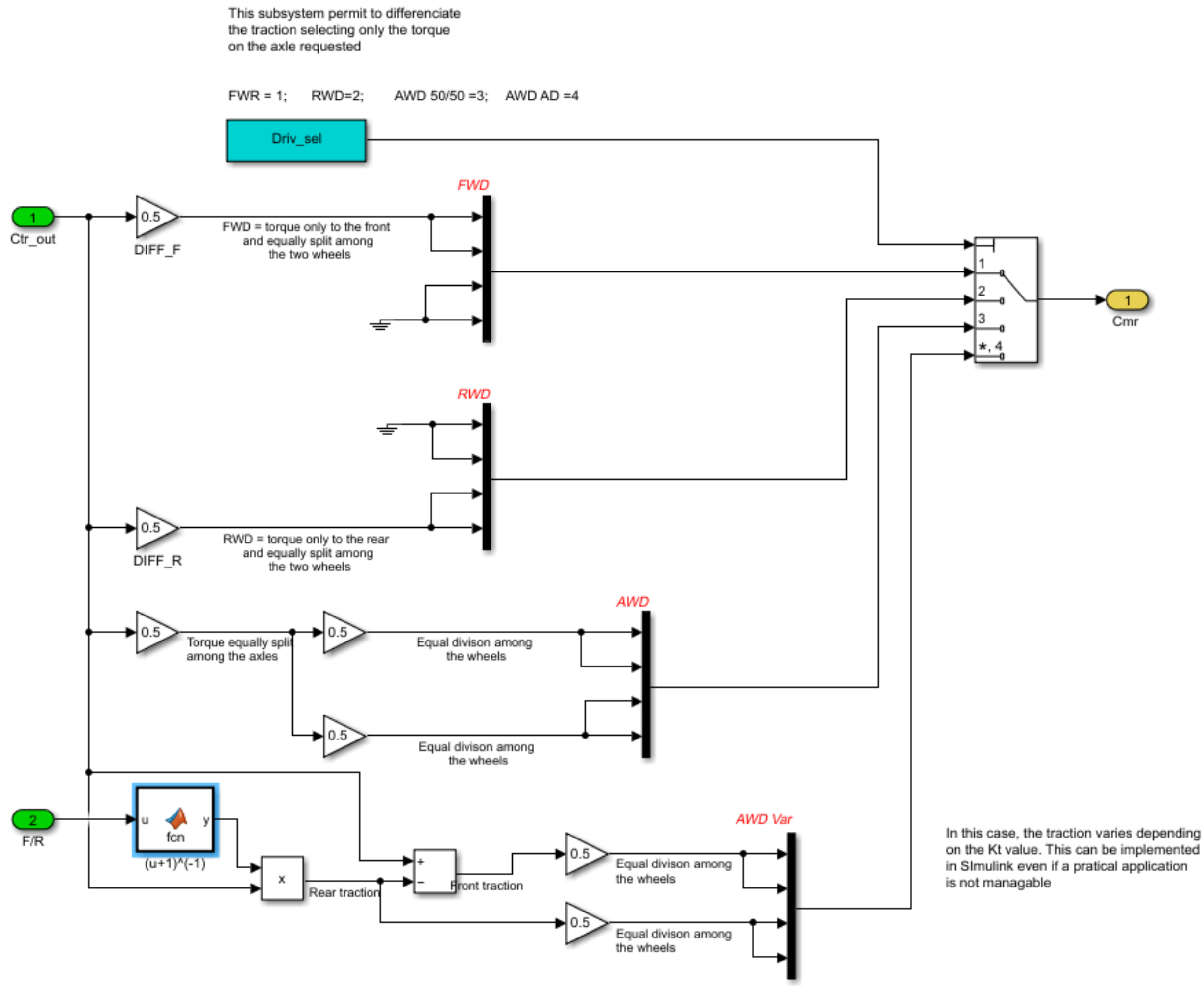
Following the same concept adopted for the speed, also the torque can be equally splitted among axles and sides according to the driving scenario selected. However, an **Adaptive AWD** is proposed. The AWD is basically a 50/50 torque splitter (also called 4WD for commercial purpouse), however in ideal coniditons the K_t factor which is the coefficent representing how the torque is being split between front and rear axle, has to vary according to the vertical forces applied by the wheel!

This condition is refered as ideal since $K_t = \frac{F_{ZF}}{F_{ZR}}$ only if the velocity and accelearation could be negletcted so as $\mu_{FRONT} = \mu_{REAR}$. In this ideal situation, the torque splitting ratio should vary according to the vertical load fluctuation due to the longitudinal load transfer. For this reason, the latter take as input the two vertical forces and calculate with it the rear tracion percentage:

$T_{in} = T_R + T_F$ having the torque split defined also as $K_t = \frac{T_F}{T_R}$ from which:

$T_R = \frac{T_{in}}{1 + K_T}$.

Finally the overall torque splitting mechanism can be modelled as follows:



The simulink model can be launched by the matlab launch file:

```
run_long_dyn_stud
```

```
Longitudinal dynamics
Initial speed: 10 km/h
Road slope: 0%
Traction : FWD
Maximum velocity reached: 203.8905 km/h
```

All the results presented here are taken directly from the result of specific simualtions: Due to the variations is not covenient to set up a live script which launches dozens of simulations only to comment the final results.

REQUESTS:

- Start from rest shifting from I to III, check if the vehicle can reach the maximum velocity. Verify the maximum speed on flat road considering FWD, RWD and AWD.

The maximum velocity is directly provided as an output from the general scope in the mode, therefore it is a matter of only setting the simualtion and make runs for each WD case.

Traction: FWD; Max Speed = 203.95 km/h

Traction: RWD; Max Speed = 203.75 km/h

Traction: 4WD; Max Speed = 204.43 km/h

Traction: AWD; Max Speed = 203.43 km/h

→No matter the traction system, the car reaches the maximum speed value founded in the previous exercise, confirming that the model developed is correct.

- Evaluate the maximum slope that can be climbed with a front (FWD), rear (RWD) or all wheel drive (AWD) vehicle (initial speed $v_x = 10 \ km/h$)

Since the slope of the ground is a parameter given to the model (it should be an exogenous one, to be precise), to verify the maximum slope it is necessary to set a certain inclination and then see if the simulation stops. In fact, there is a stop block whenever the vehicle velocity goes to zero, meaning that it is not proceeding foward but it is starting to go backwards.

The following results have been obtained in this way: set an inclination and launch the simulation with the traction system required, until the time of simulation reaches values close enough to 10 seconds. By trial and error, closer and closer values to 10 seconds have been obtained until a satisfactory level was reached. Here the slope given was set as the maximum one.

Traction : FWD; Road slope: 37.13% (t_stop = 9.988sec) $\rightarrow \alpha = 20.37\,\text{deg}$

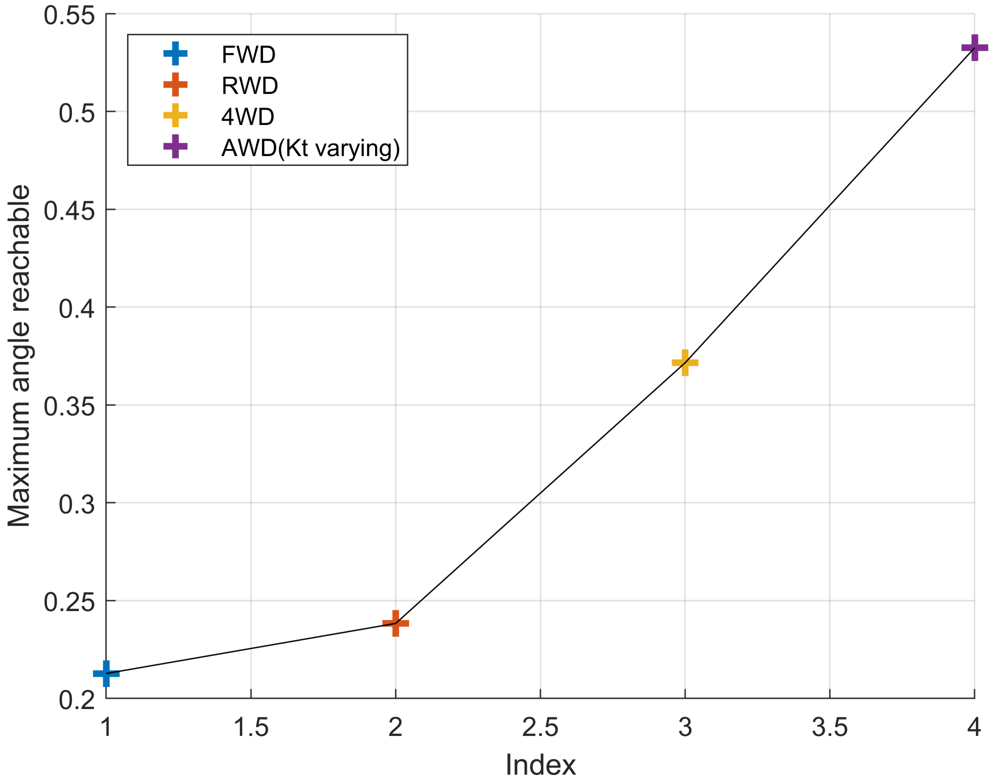
Traction : RWD; Road slope: 41.6% (t_stop=9.89sec) $\rightarrow \alpha = 22.59\,\text{deg}$

Traction : AWD 50/50; Road slope: 64.85% (t_stop= 9.859sec) $\rightarrow \alpha = 32.96\,\text{deg}$

Traction : AWD Active Diff; Road slope: 92.95% (t_stop=9.967sec) $\rightarrow \alpha = 42.91\,\text{deg}$

→The maximum slope reachable higly depend on the traction system adopted. The trend clearly shows that for climbing performances an AWD is way more competitive. Having the traction distributed in all wheels permit to develop forces which let the vehicle to stay attached to the ground even with high inclinations.

```
imax_FWD = 37.13/100; alpha_maxFWD = atand(imax_FWD/100);
imax_RWD = 41.6/100; alpha_maxRWD = atand(imax_RWD/100);
imax_4WD = 64.85/100; alpha_max4WD = atand(imax_4WD/100);
imax_AWD = 92.95/100; alpha_maxAWD = atand(imax_AWD/100);
figure(1); hold on; grid on;
plot(1,alpha_maxFWD,'+','linewidth',2.5,'markersize',10);
plot(2,alpha_maxRWD,'+','linewidth',2.5,'markersize',10);
plot(3,alpha_max4WD,'+','linewidth',2.5,'markersize',10);
plot(4,alpha_maxAWD,'+','linewidth',2.5,'markersize',10);
plot([alpha_maxFWD alpha_maxRWD alpha_max4WD alpha_maxAWD],'k','linewidth',0.5);
xlabel('Index'); ylabel('Maximum angle reachable');
legend('FWD','RWD','4WD','AWD(Kt varying)','location','northwest')
```



NOTE: Gear shifting up to 3rd in some cases due model incapacity do represent the reality once the vehicle slips and goes backwards.

COMPARISON: Previous exercise - Actual Simulink model

Doing a direct comparison between the previous Matlab code and the Simulink model adopted, it is possible to observe the differences in matter of performances. In particular the `MATLAB` vehicles shows better climbing performances. One of the effects is due to the different mass distribution:

$$MATLAB : a = 1.1, b = 1.5 \rightarrow 42.31\% \, front$$

$$SIMULINK : a = 1.2, b = 1.4 \rightarrow 46.15\% \, front$$

However, even adopting the same data (the simulink model was adapted to the Matlab data), the cars still shows different behaviours. This occurs since there is a fundamental difference between the two:

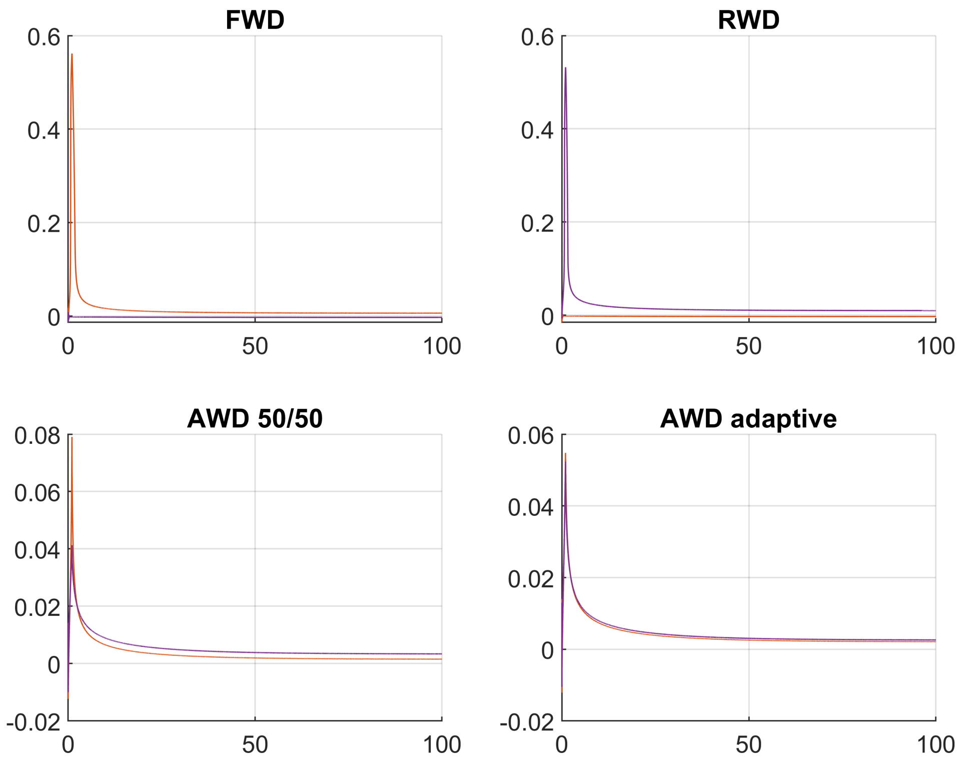
Matlab hypothesied the maximum slope, meanwhile Simulink mesure it. The first calculate the maximum slope as $i_{\max}\big|_F = \tan \alpha_{\max}\big|_F = \dfrac{\mu b(1 + 1/K_T)}{L + \mu h_G(1 + 1/K_T)}$, meanwhile in the Simulink model the car is actually launched and the maximum slope is seen when the car stop (which is when the simulation stops). Moreover, the Simulink model takes into account effect which are not present in the MATLAB calcualtion, like the rolling resistance term (make reference to the demonstration on the slides).

RECAP QUESTION: Why MATLAB and Simuink models provide different results even if they are simulating the same dynamics?

- Check the tire slip at maximum speed and try to explain the former result.

```
figure(2); %create new figure
h1 = openfig('FWD_slip.fig','reuse'); % open figure
ax1 = gca; % get handle to axes of figure
h2 = openfig('RWD_slip.fig','reuse');
ax2 = gca;
h3 = openfig('4WD_slip.fig','reuse'); % open figure
ax3 = gca; % get handle to axes of figure
h4 = openfig('AWD_slip.fig','reuse');
ax4 = gca;
% test1.fig and test2.fig are the names of the figure files which you would % like to copy into

h5 = figure; %create new figure
s1 = subplot(2,2,1); title('FWD');grid on;%create and get handle to the subplot axes
s2 = subplot(2,2,2); title('RWD');grid on;
s3 = subplot(2,2,3); title('AWD 50/50');grid on;
s4 = subplot(2,2,4); title('AWD adaptive');grid on;
fig1 = get(ax1,'children'); %get handle to all the children in the figure
fig2 = get(ax2,'children');
fig3 = get(ax3,'children');
fig4 = get(ax4,'children');
copyobj(fig1,s1); %copy children to new parent axes i.e. the subplot axes
copyobj(fig2,s2);
copyobj(fig3,s3);
copyobj(fig4,s4);
```



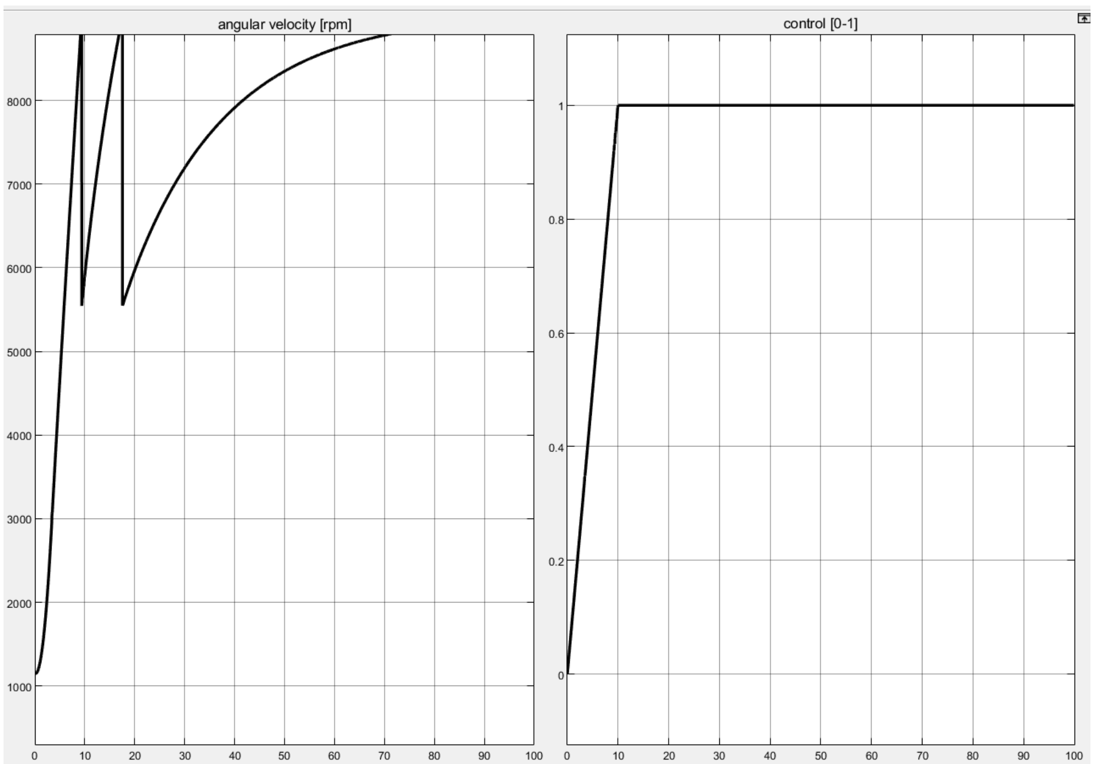
<u>NOTE</u>: Each figure has been uploaded since it would be too complex to run a simulation, store the plot and run again the simulation. Or to be honest, it's too complex to do it right now.

As expected, the slip is consistently present ony in that axle where the driving is applied (FWD and RWD). Physically, the car is drifting since it is trying to apply a certain wheeling torque but the tyre cannot develop enough grip to expolit it.

Regarding splitted torque instead, in these cases the slip never reached significant values, suggesting that the car adequately develop traction forces.

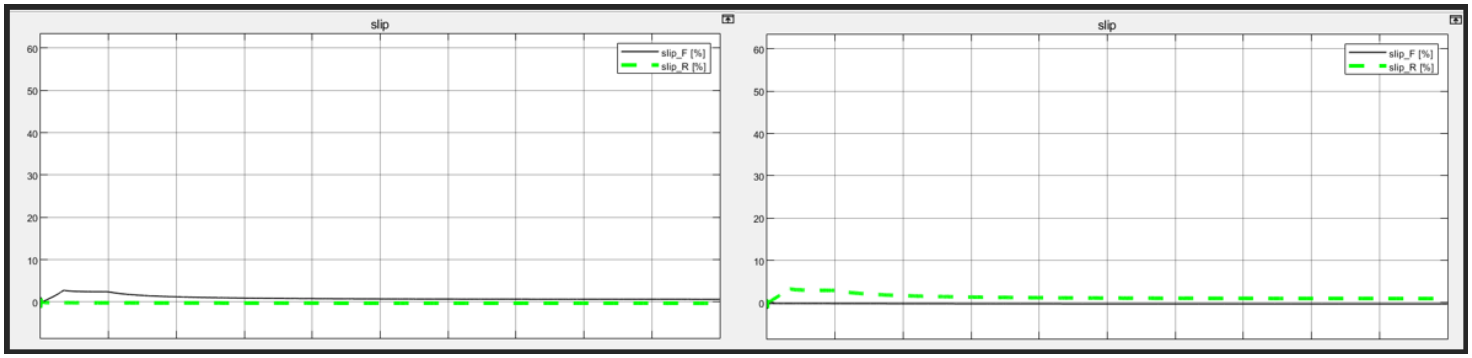
- Limit the rising slope of the motor command so that the maximum torque is reached after 10 s. Shift the gear at the maximum electric motor speed (9000 rpm).

By changing the control it means that thecdriver is less aggressive over the acceleration pedal. Therefore it is resonable to expect that the vehcile is capable to explot better its traction forces, decreasing in this way the slippage.



Fortunately, that is exactly what happens to the simualtions, showing that for both FWD and RWD the slip will be minor respect to the previous cases. This is also helped by the increasing of the gearshifting limit, since increasing it permit to exploit better the traction forces. Shifting too early in a smooth acceleration has as effetc to cut out the power trasmitted to the tyre ground contact, loosing some grip developing capacity.

Furthermore no significant changes have been observed regarding the maximum velocity, suggesting that in the aim of maximum velocity how the vehicle starts its acceleration does not have significant relevance. Itsead it could in case of a drag race, but that's another story.



RECAP QUESTION: What happens if the up shifthing is applied at higher rpms with a slower acceleration?

- Compute the speed difference to be synchronized during 1st to 2nd and during 2nd to 3rd gear shift.

For speed difference to be syncronized it means the difference of engine angular velocity when the gear is engaged. In the standard simulation its value is of around 3000 rpm (from 8000 rpm to 5000 rpm, visible clearly from the slides or in the scope signal).

With the difference proposed (9000 gear shifting and acceleraton command smoother) this delta of rpm are (Taken directly from the vector plotted in the Simulink scope):

First to second: 9000 rpm 5544.18 rpm

Second to third: 9000 rpm 5546.55 rpm

Suggesting that this rpm difference increases up to 3455 rpm. Since the motor reaches higher velocity, it will have bigger inertias, meaning that when the motor will engage with the following gear the rpms will be higher than the standard case.

- Repeat the test changing the gear at 4500 rpm, compute the speed difference.

Traction: FWD; Max Speed = 204.1 km/h

Traction: RWD; Max Speed = 203.70 km/h

Traction: 4WD; Max Speed = 204.46 km/h

Traction: AWD; Max Speed = 203.47 km/h

Every simulation shows an higher maximum velocity, even if the improvements are very small (RWD improves of 0.002 km/h). Please be aware that in this case the command has been set again to a very steep ramp which means a very aggressive acceleration. Before it has been said that up shifting too early could imply to reduce the grip capacity to imrpove. However this is is true for a smooth acceleration (it takes 10 seconds to reach the accelerator's end pedal).

In fact, considering an aggressive acceleration, it is seems that is better to shift gear for lower values of motor speed. This is due to the fact that in the electric motor adopted, angular velocity and torque are inversely proportional with fixed power value. Which means that for lower motor speed the car is able to exploit better traction forces, which consequently implies higher traction = maximum speed increased.