Aston University
BIRMINGHAM UK

Model for calculation of propulsion system and battery design of a Formula Student electric vehicle

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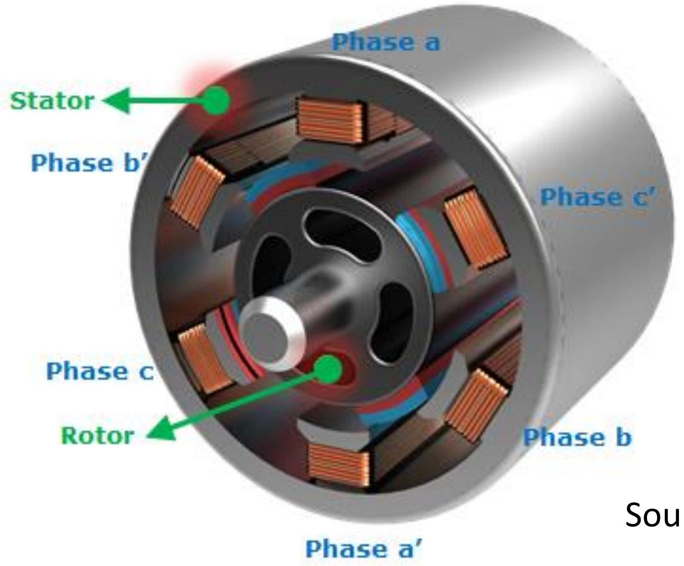
Outline

- Existing literature of propulsion systems
- Methodology of creating the models for DC and PMSM motor
- Results and discussion

Motors and power electronics

Key Advancements

- SiC & GaN improve power electronics with better thermal, electrical performance, and faster switching
- PMSM motors use vector control which deal with toque control both when the speed changes and when load variations occur
- DC motors use simple PWM with electronics such as h-bridges



Source: functionbay.com

DC Motor	PMSM
Cost-effective and simpler	More expensive but highly efficient
Robust and reliable	Offers higher torque-to-weight ratio
Requires lower control strategy complexity	Needs advanced control strategies
Lower cooling requirements	Needs advanced cooling systems

Thermal management and batteries

Other technologies for thermal management include:

- Phase-changing materials
- Advanced coolants
- Experimenting with 3d printed cooling channels
- Strategic placement of cooling elements

Developments for batteries:

- Solid-state batteries for their increased safety and energy density
- Innovations in cell chemistry and battery management systems for high efficiency and longer lifespans
- Fire-resistant materials
- Emergency disconnect system to enhance safety

Air cooling	Liquid cooling
Low cost, low maintenance	Even temperature distribution
Lightweight	high heat capacity for high power loads
Lacks even temperature distribution	High weight and costs
low energy consumption	High energy consumption

Methodology

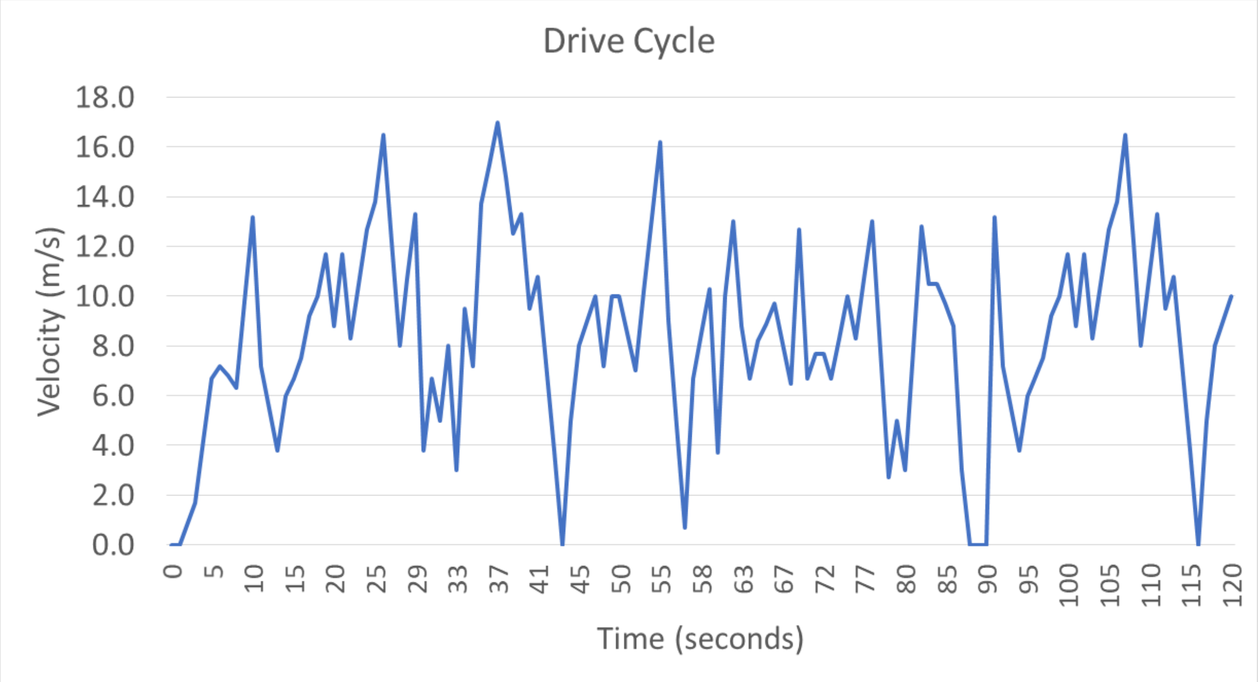


Table 1- Parameters from Formula student team at Aston University

PARAMETER	VALUE
Mass	320 kg
Battery Voltage	600 V
Frontal Area, A_f	0.385 m^2
Tire diameter	0.404 m^{-1}
Horizontal distance from CG to front axle	0.991 m
Horizontal distance from CG to back axle	0.534 m
CG height above the ground	0.33 m

Table 2-Parameters for worst case scenarios

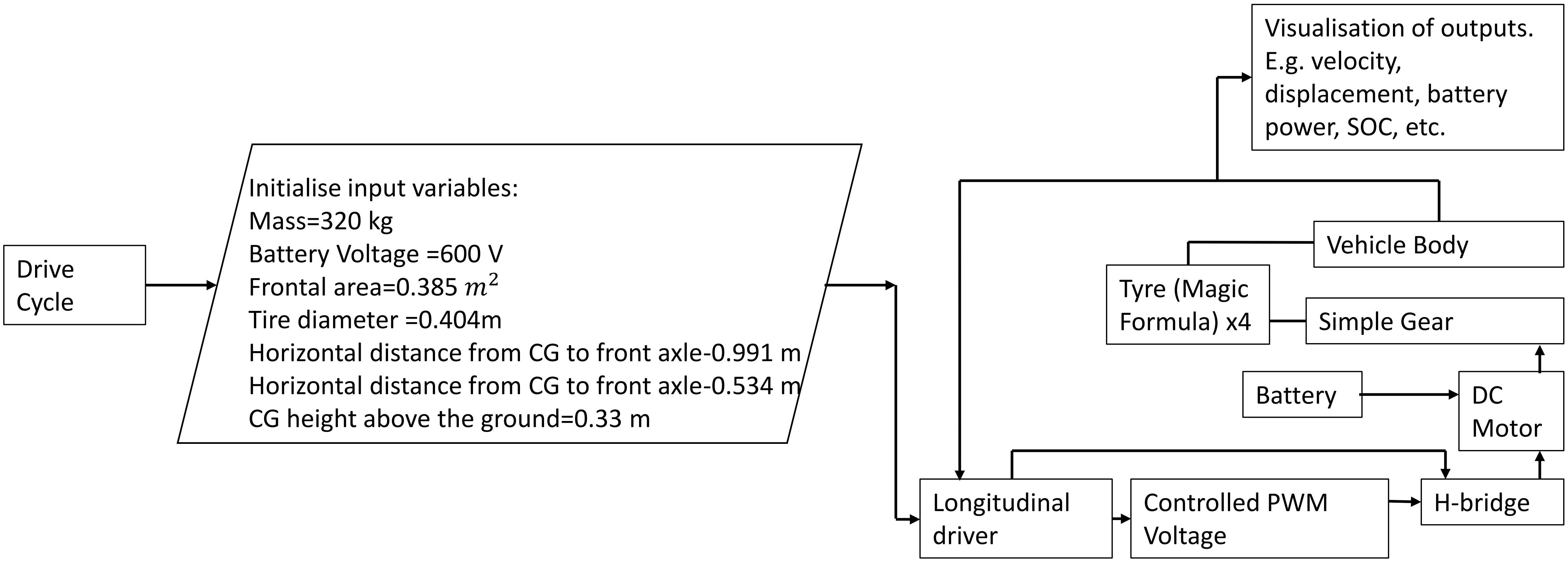
PARAMETER	VALUE
Drag coefficient, Cd	0.35
Air density	1.293 kg/m^3
Coefficient of rolling resistance, C_{rr}	0.015
Gravity, g	9.81m/s^2
Gear efficiency	80%

Methodology

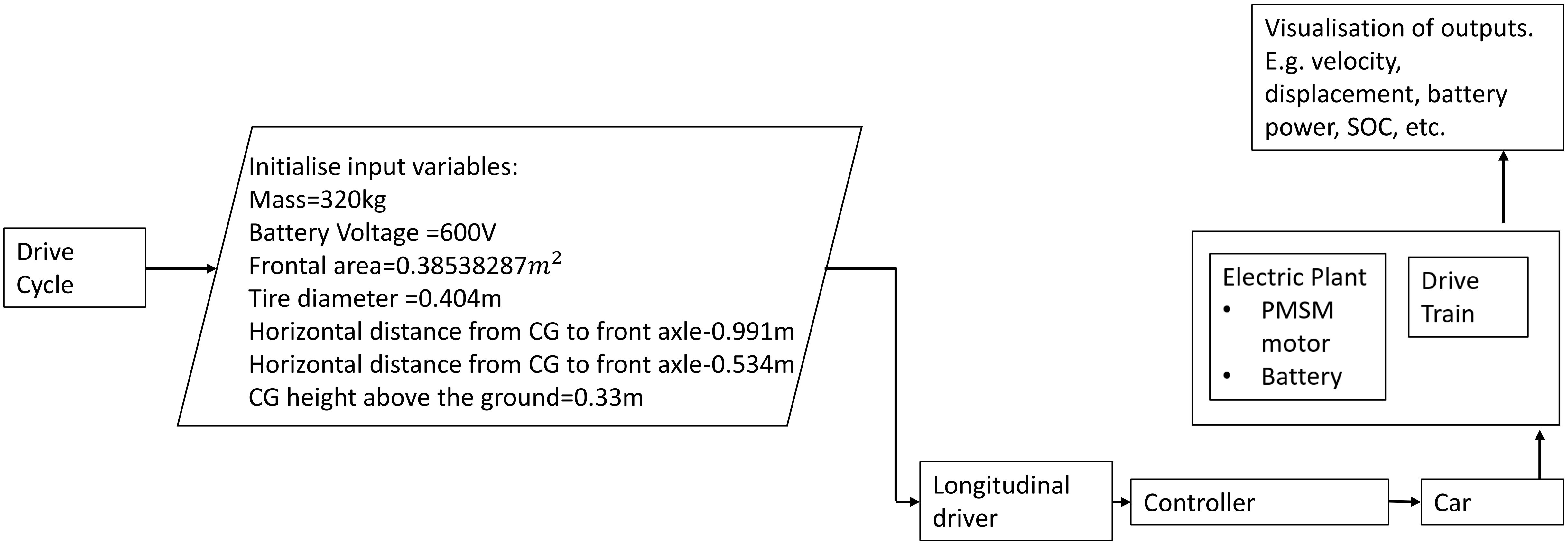
Blocks	Input parameters
DC motor	Armature inductance:12×10^{-6} No-Load speed:9000rpm Rated speed (at rated load):8000rpm Rated Load (Mechanical power):30 Rated DC supply Voltage:330V
H-bridge	Output voltage amplitude:330V
Tire (magic formula)	Tire radius:0.404/2m
Vehicle body	Mass:320kg Horizontal distance ffrom CG to front axle:0.991m Horizontal distance ffrom CG to rear axle:0.534m CG height above ground:0.33m Frontal Area:0.38538287m^2 Drag coefficent:0.35
Simple gear	Gear ratio:3.7
Battery	Nominal Voltage: 600V Internal resistance:15mohms Cell Capacity:216Ahr Voltage V1 when charge is AH1:16.8 Charge AH1 when no load voltage is V1:4.5
Longitudinal driver block	Proportional gain:2000 Integral gain:500 Velocity feed-forward:100 Nominal speed:20
Controlled PWM voltage source	PWM frequency:2000Hz Simulation mode:averaged
Controlled Voltage source	Standard settings
Solver configuration	Standard settings
Controlled current source	Standard settings
Electrical reference	Standard settings
Mechanical rotational reference	Standard settings
Simulink-PS converter	Standard settings

PS-Simulink converter	Standard settings
Scope	Increase the ports
From spreadsheet	Add the excel sheet with the edited drive cycle
Voltage sensor	Standard settings
Current sensor	Standard settings
Derivative	Standard settings
Integrator	Standard settings
Rate transition	Standard settings
Discrete-time integrator	Standard settings
Gain	Depending on situation
Sum	Standard settings
Inertia	Standard settings
Constant	0 or 1 depending on situation

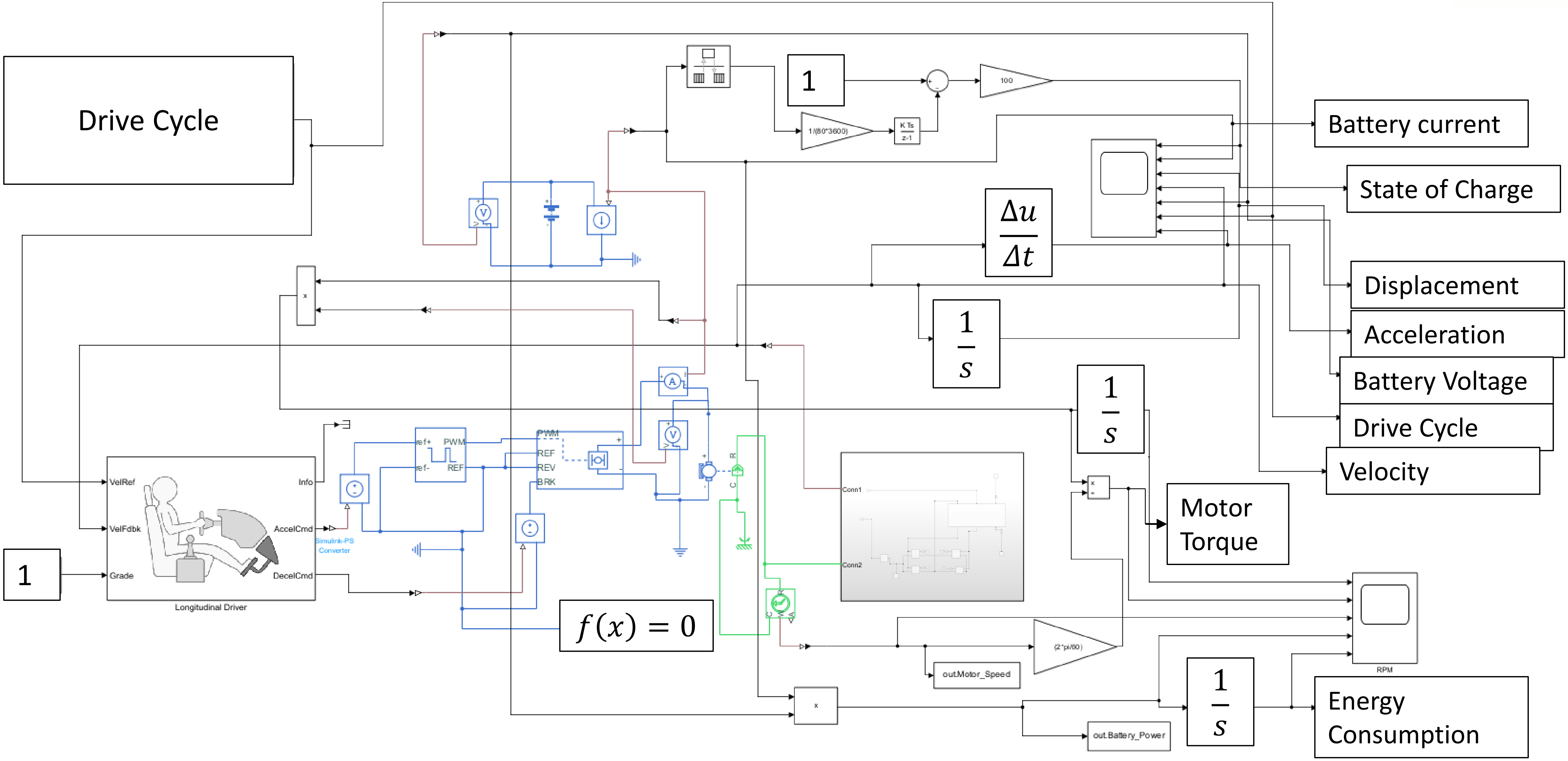
Flow diagram of DC motor model



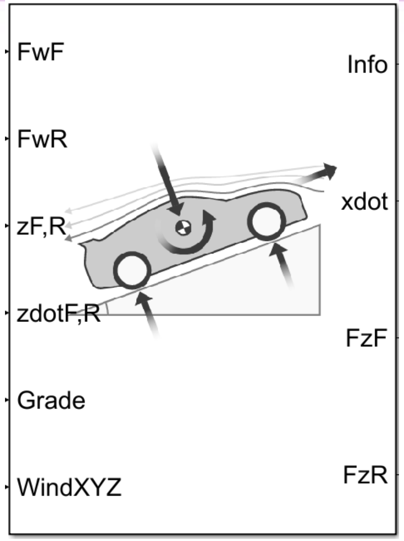
Flowchart of PMSM motor model



DC motor model schematics



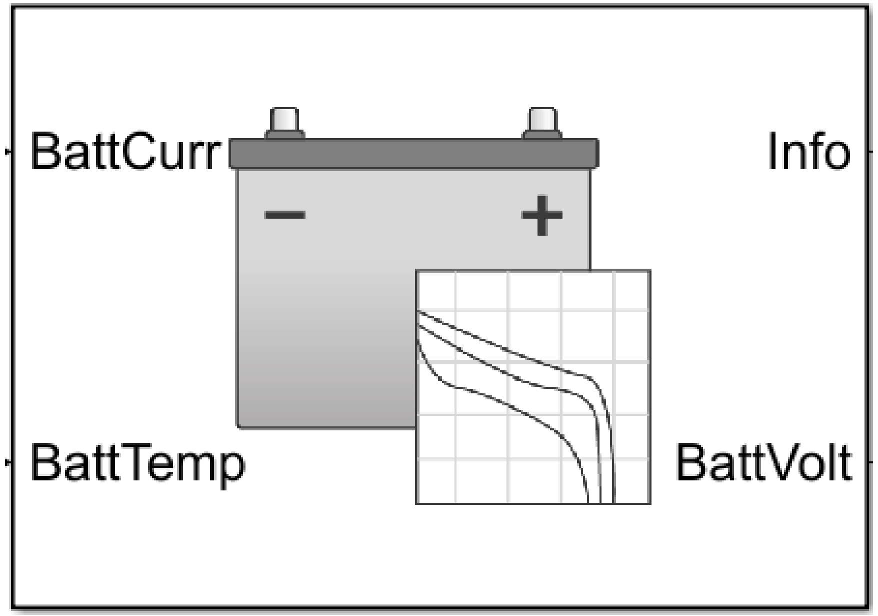
PMSM block parameters



Vehicle Parameters

▾ Longitudinal Parameters

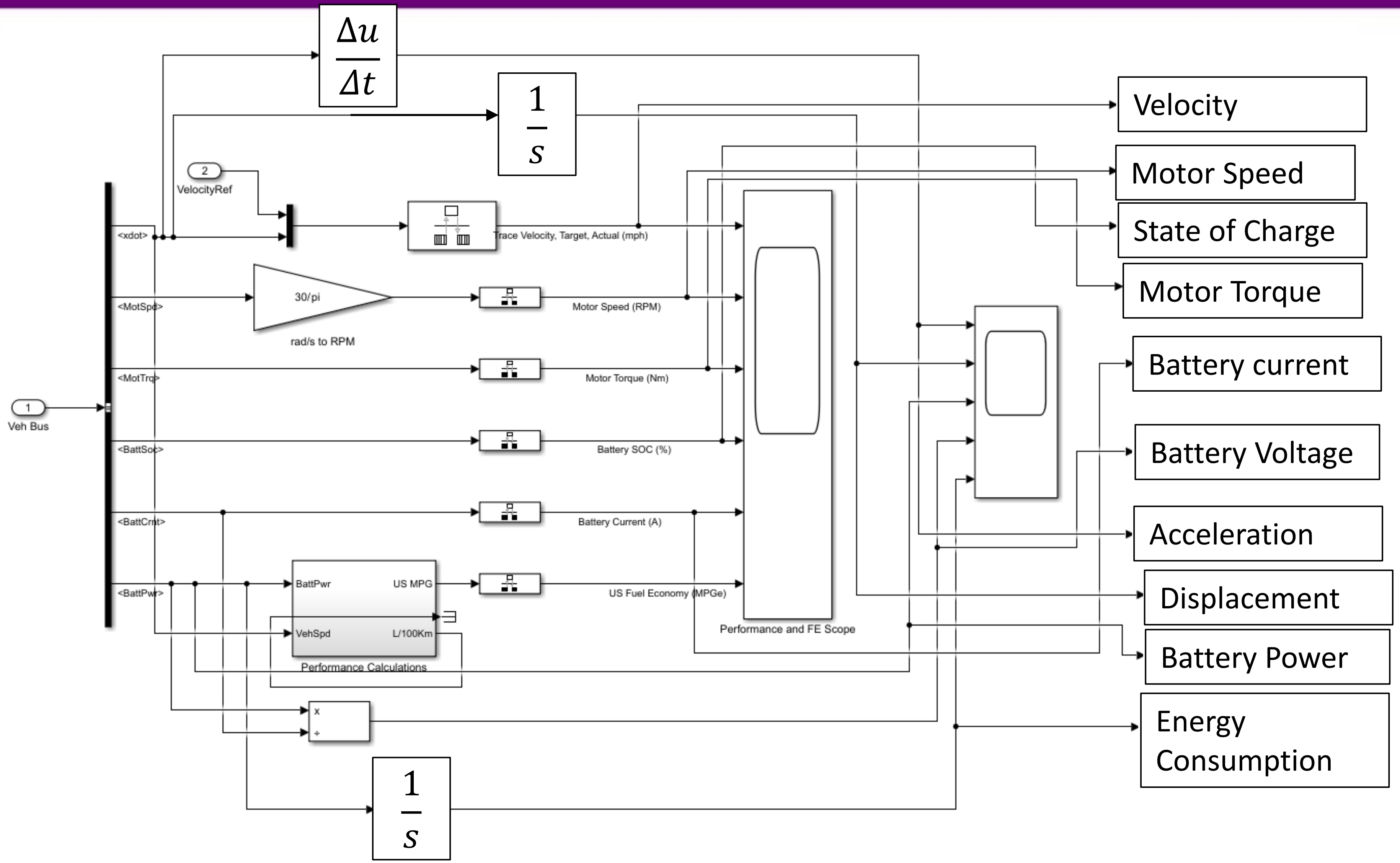
Number of wheels on front axle, NF []:	NF	2
Number of wheels on rear axle, NR []:	NR	2
Mass, m [kg]:	Mass	320
Horizontal distance from CG to front axle, a [m]:	a_CG	1.188
Horizontal distance from CG to rear axle, b [m]:	b_CG	1.512
CG height above axles, h [m]:	h	0.5
Longitudinal drag coefficient, Cd []:	Cd	0.28
Frontal area, Af [m^2]:	Af	0.38538



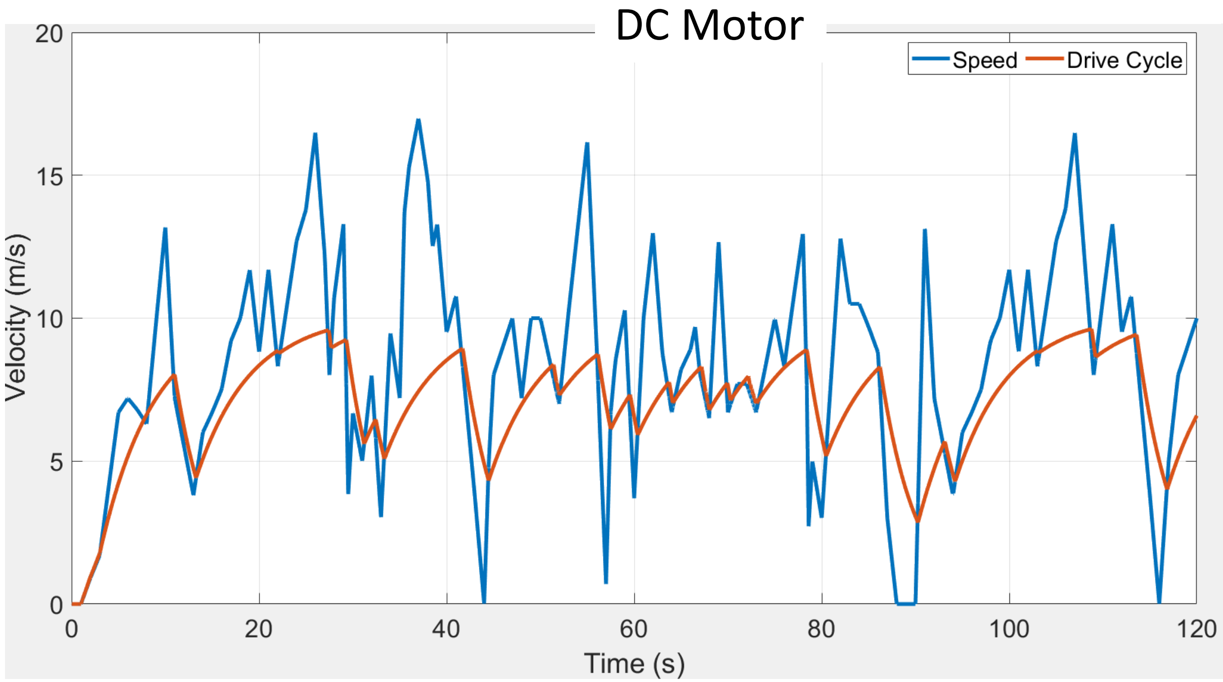
Parameters

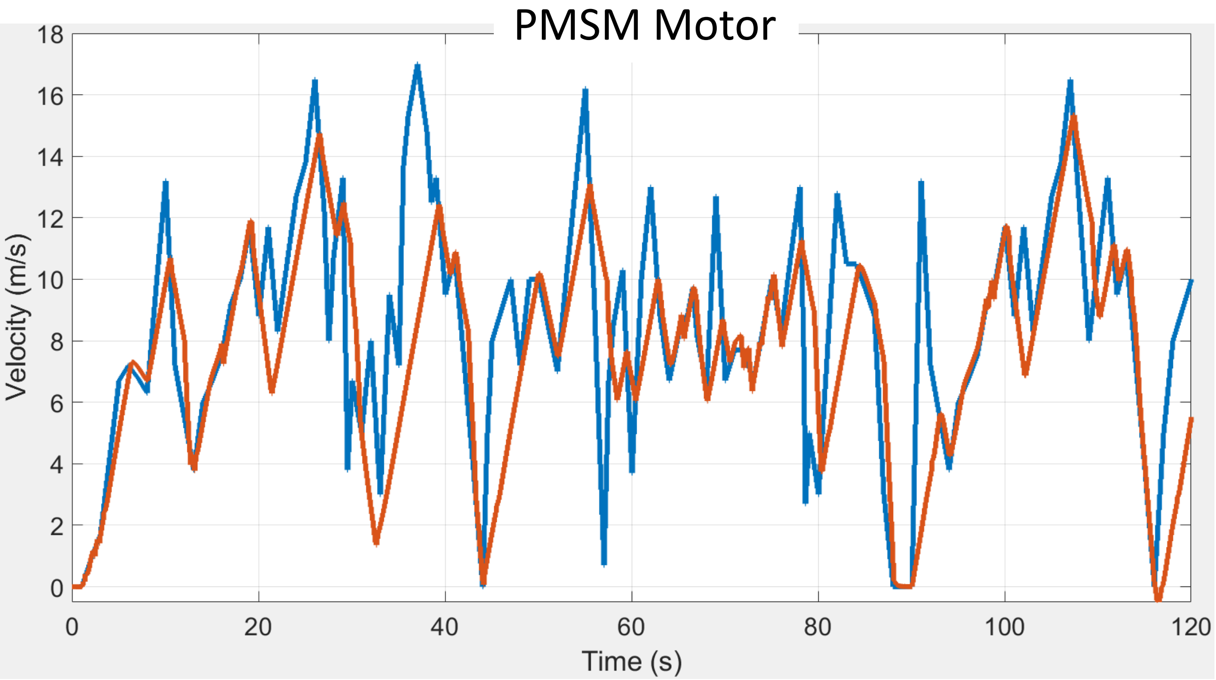
Rated capacity at nominal temperature, BattChargeMax [Ah]:	BattChargeMax	4.8
Open circuit voltage table data, Em [V]:	Em*1	<100x1 double>
Open circuit voltage breakpoints 1, CapLUTBp []:	CapLUTBp	<1x100 double>
Internal resistance table data, RInt [Ohms]:	RInt	<4x100 double>
Battery temperature breakpoints 1, BattTempBp [K]:	BattTempBp	[263.15,273.15,298.15,313.15]
Battery capacity breakpoints 2, CapSOCBp []:	CapSOCBp	<1x100 double>
Number of cells in series, Ns []:	Ns	156
Number of cells in parallel, Np []:	Np	31
Initial battery capacity, BattCapInit [Ah]:	BattCapInit*BattSocInit/.75	3.6

PMSM model schematics



Results: Motor velocity profile vs drive cycle

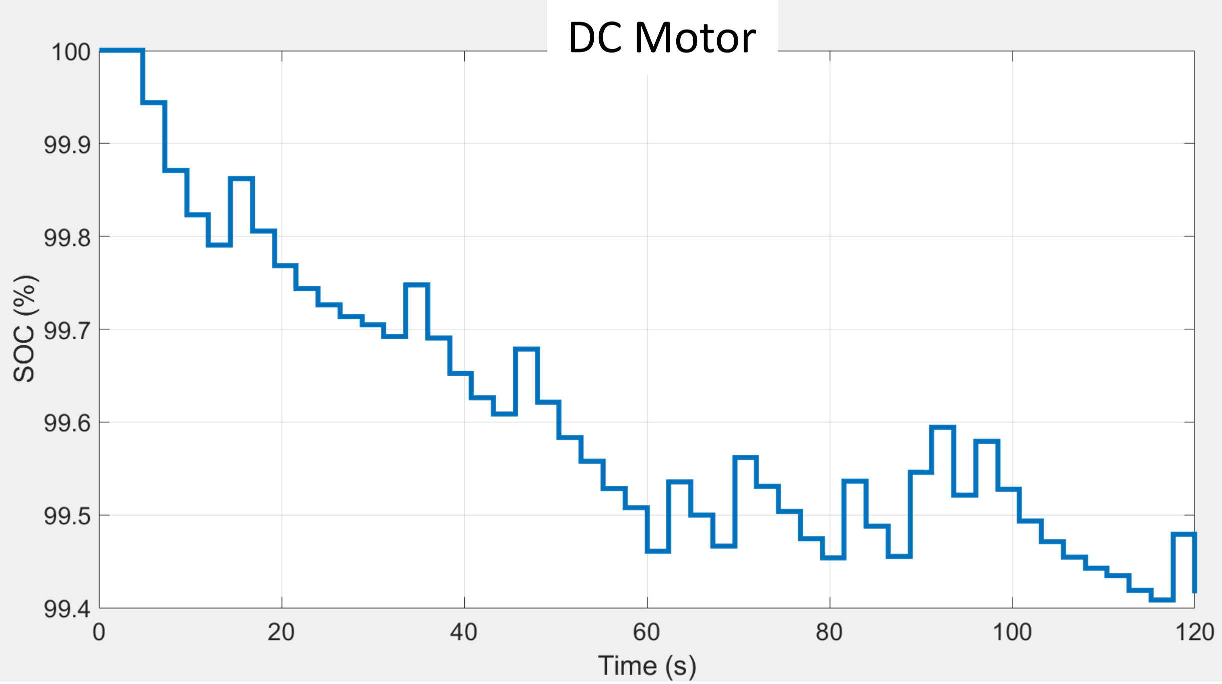


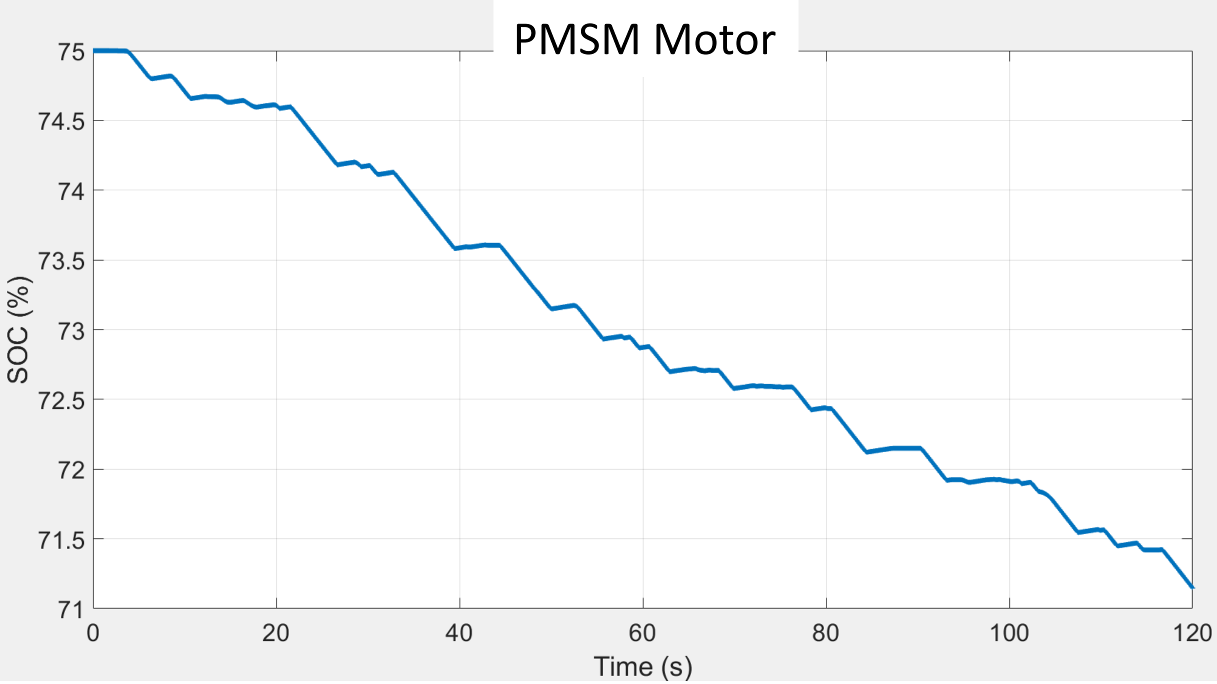


- DC motor does not follow the drive cycle adequately
- DC motor peaks at 9.625 m/s as opposed to the drive cycle peak at 17m/s
- Model velocity struggles to switch between acceleration and deceleration

- PMSM Motor generally follows drive cycle satisfactorily
- Peak model velocity reaches 15.338 m/s
- Rapid acceleration/deceleration transitions (e.g. at 73 s).
- Occasional struggles (e.g. at 29 s), indicating possible control issues.

Results: state of charge (SOC)

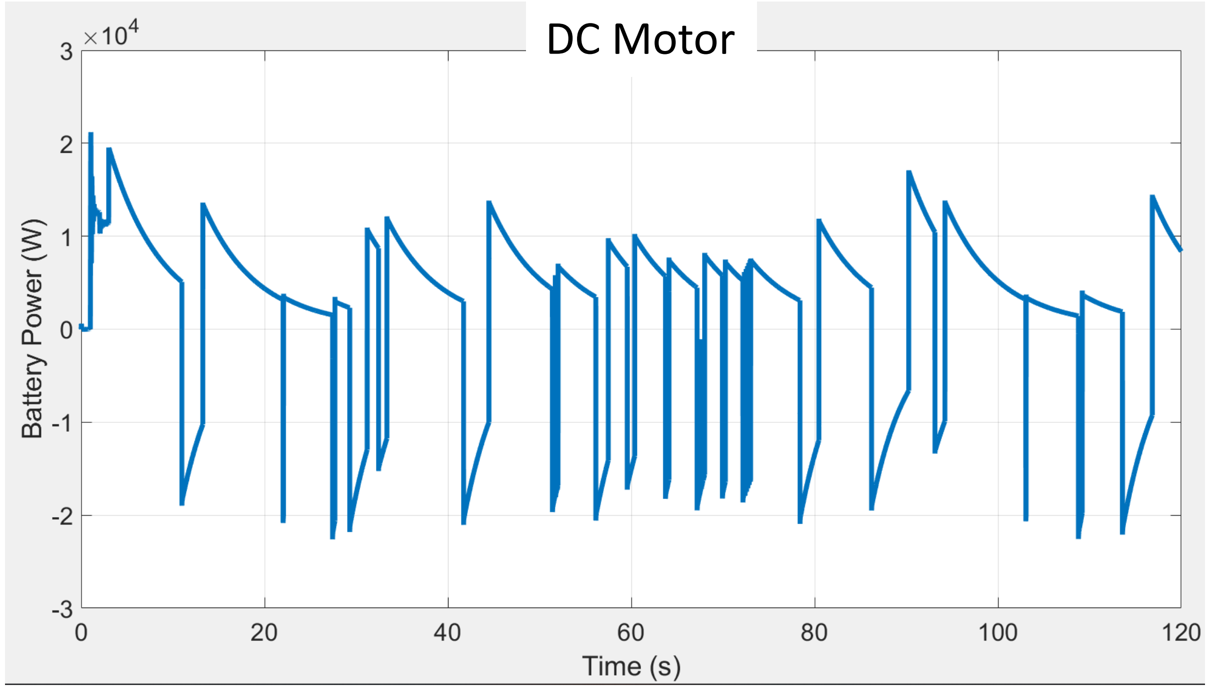




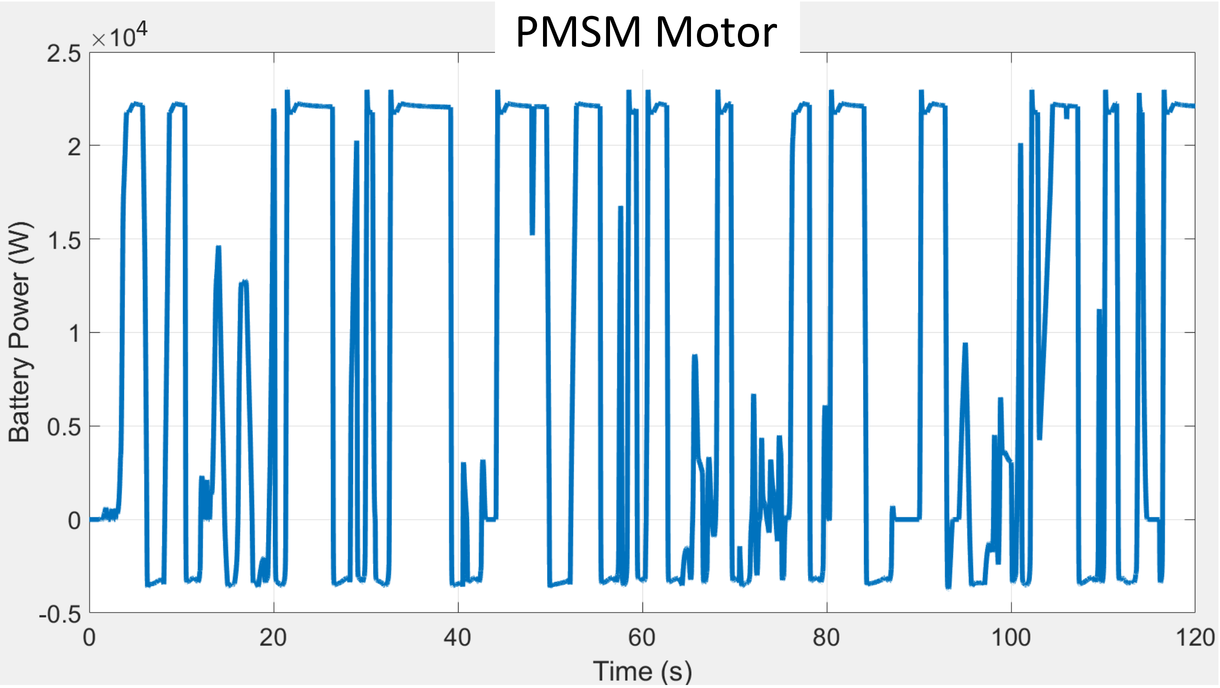
- SOC does not decrease linearly but rather in a step-like fashion
- This pattern shows that the vehicle energy consumption is not constant but occurs in bursts
- SOC decreases from 100% to 99.4% in 120 s

- SOC decreases steadily from 75% to 71% in 120 s
- There are no sharp drops, suggesting stable power usage without abrupt discharge events
- There are no increases in SOC, indicating no energy recovery through regenerative braking

Results: Battery power variation

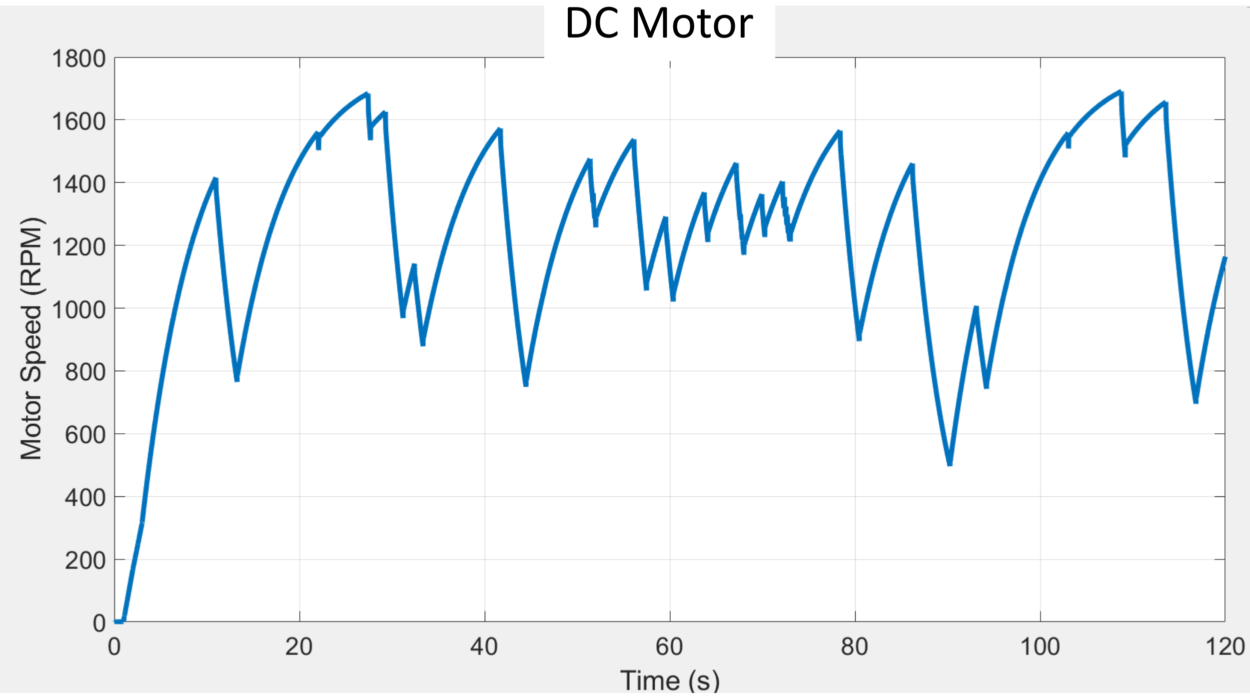


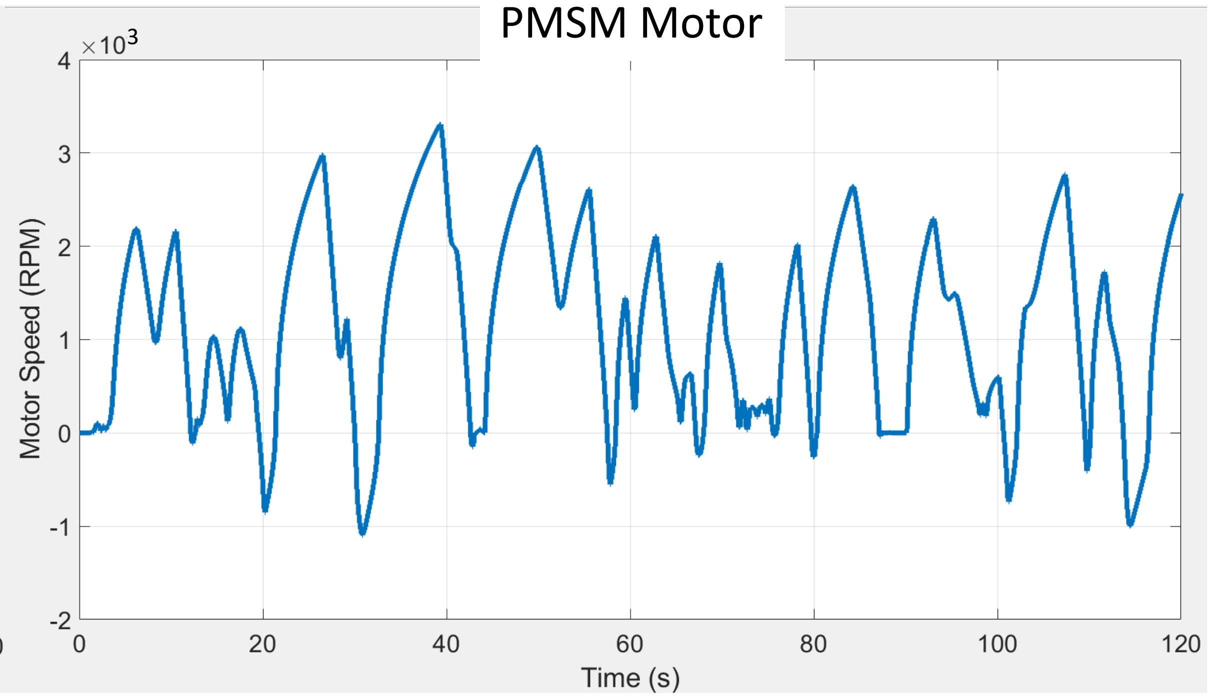
- DC motor battery power fluctuates rapidly, showing dynamic power demands and energy recovery during acceleration and braking phases
- Maximum power achieves 21 kW
- Frequent acceleration and deceleration cause rapid power spikes, which can stress the battery
- Efficiency of energy recovery system can be improved



- PMSM motor power fluctuates, showing dynamic demands and energy recovery.
- Maximum power of 23 kW
- Rapid spikes from acceleration and deceleration stress the battery, highlighting the need for efficient energy management

Results: Motor speed





- Peaks of 1700 RPM and dips near 600 RPM
- Higher rotations will lead to increased energy usage
- Fluctuations show that the control system works adequately

- Negative speed values might imply that the motor is reversing direction, indicating further adjustments are necessary in the model
- Maximum speed of 3500 RPM is attained

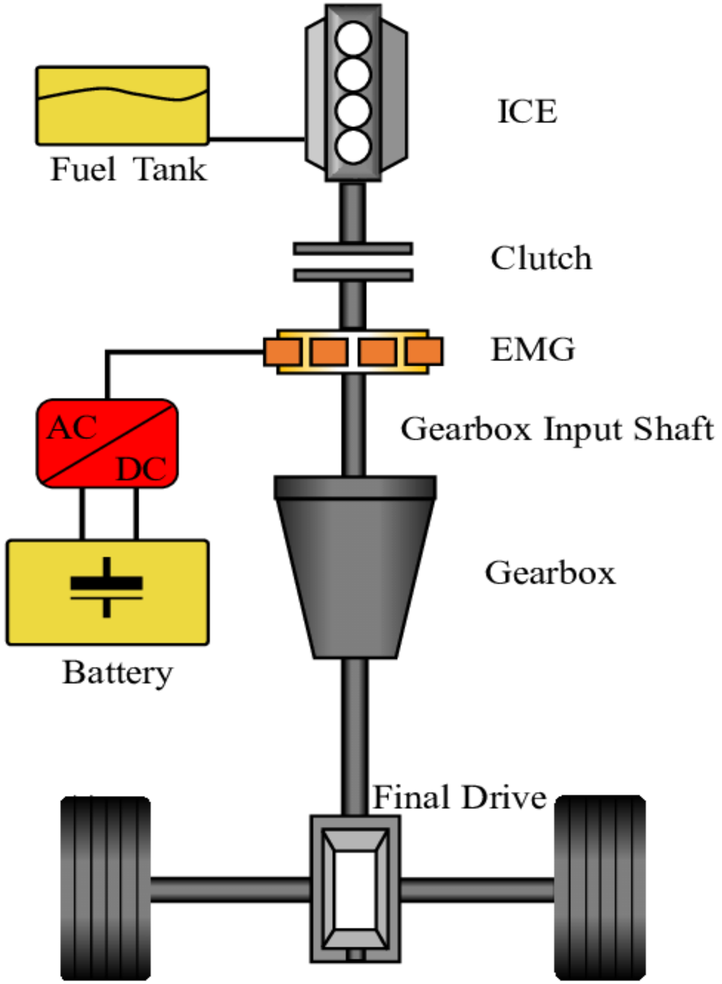
Conclusion

- Permanent Magnet Synchronous Motor (PMSM) demonstrated superior performance, closely following the drive cycle with higher top speeds, improved acceleration, and more efficient use of energy compared to the Direct Current (DC) motor

- Both motor types fell short of fully achieving the target drive cycle goals, particularly in reaching maximum speeds and maintaining consistent power consumption, indicating a need for refined control strategies

- Both motors showed irregularities in acceleration/deceleration transitions, highlighting potential control system issues, especially during dynamic racing conditions. Further optimization of the control systems is required to ensure smoother performance

- Future works could improve the model by considering better control algorithms, thermal management systems and other powertrain types such as hybrid powertrains.



Source: (PDF) Sensor Range Sensitivity of Predictive Energy Management in Plug-In Hybrid Vehicles

Thank you for listening

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