ME 199 THESIS DEFENSE

CONTROL IMPLEMENTATION IN A SERIES-PARALLEL HYBRID DRIVETRAIN : AN INVESTIGATION INTO FUEL-CONSCIOUS OPERATION

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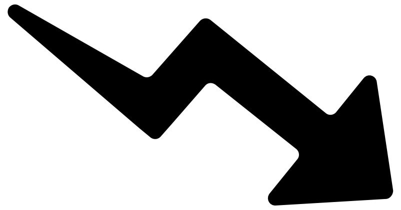
MAY 30, 2025

PUBLIC TRANSPORT MODERNIZATION PROGRAM*

efforts to make public transportation system-efficient and environmentally friendly

-12% Euro 4 fuel efficiency vs traditional

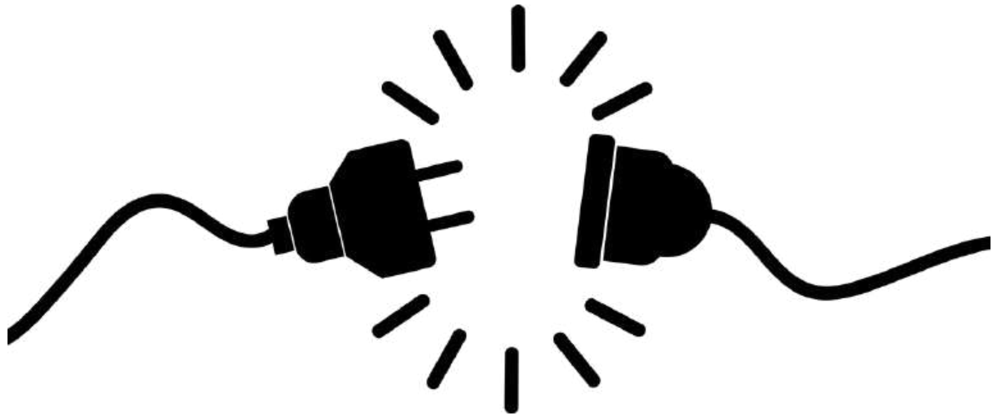


LESS FUEL-EFFICIENT IN A PERIOD OF SOARING FUEL PRICES

PHP 200,000-600,000
vs
PHP 2.5-2.6 MILLION

PHP 210,000-280,000
government subsidy

HIGH INITIAL COST AND INSUFFICIENT SUBSIDY



LACK OF INFRASTRUCTURE FOR ELECTRIFICATION

**previously the PUV Modernization Program*

WE BELIEVE

transportation solutions must be accessible as they are sustainable.

a hybrid drivetrain can be...

simplified and low-cost architecture

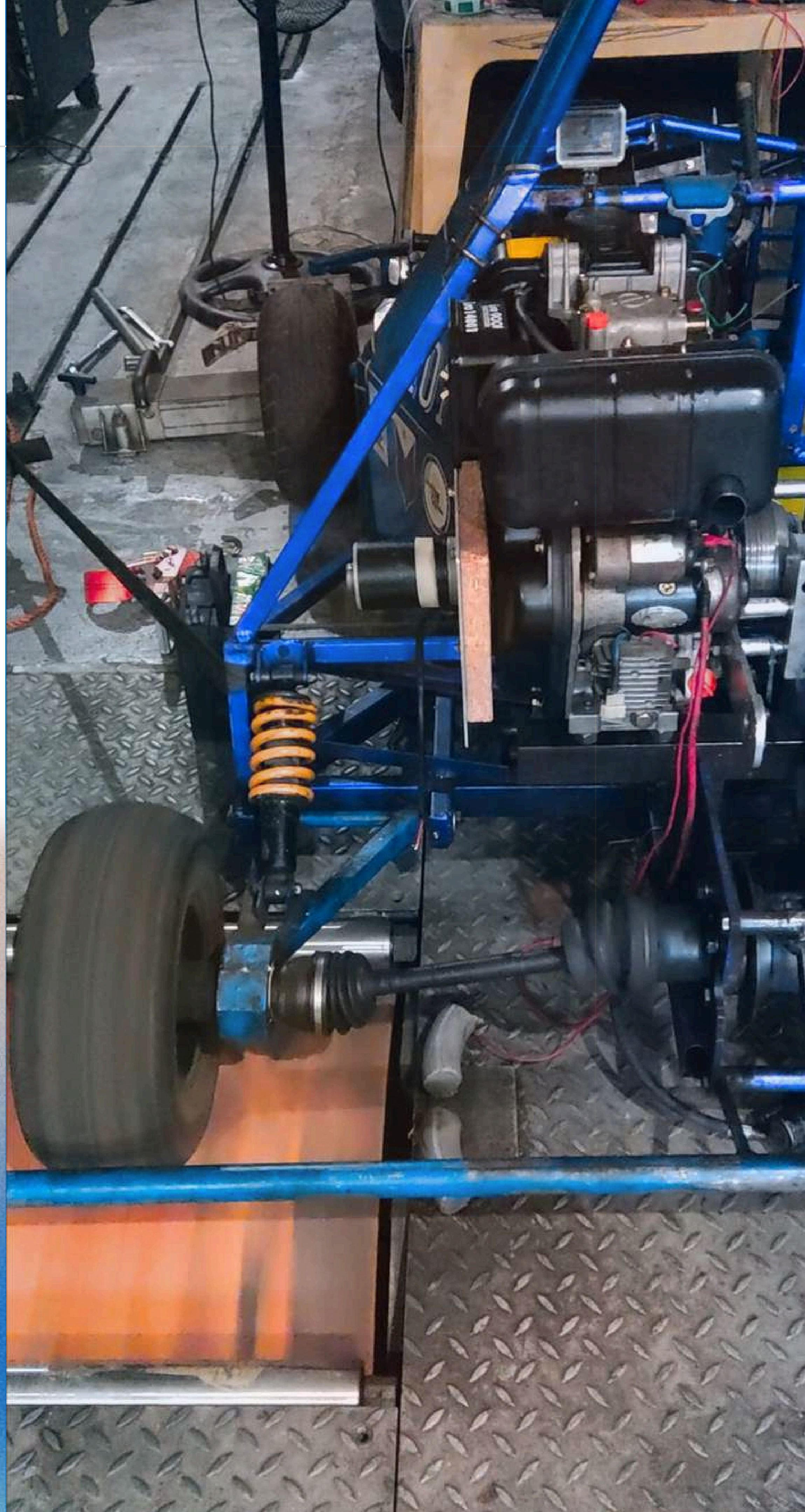
↓

retrofit-friendly

fuel-conscious

↓

sustainable and economical



a hybrid drivetrain can be...

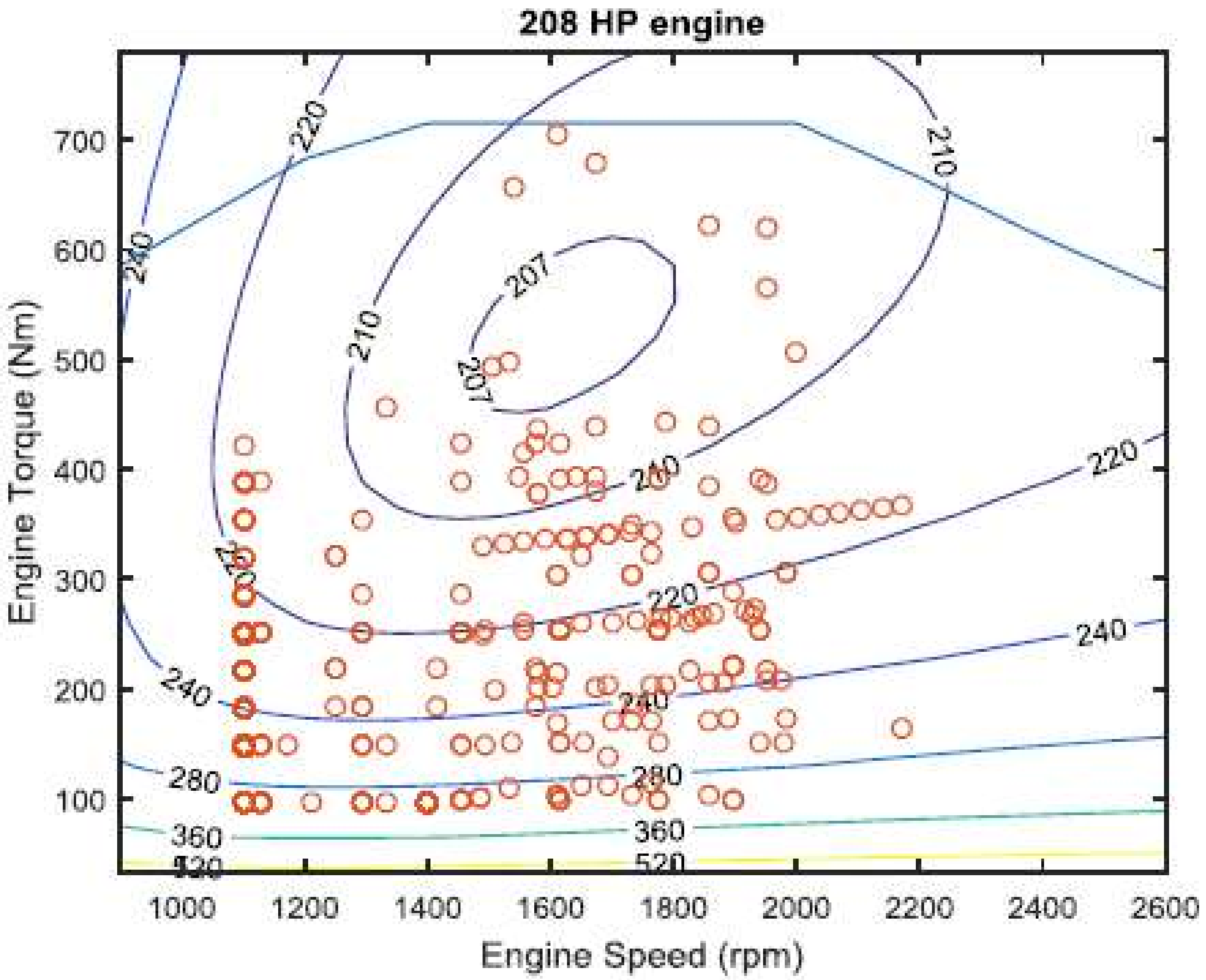
designed to target optimum engine operating points

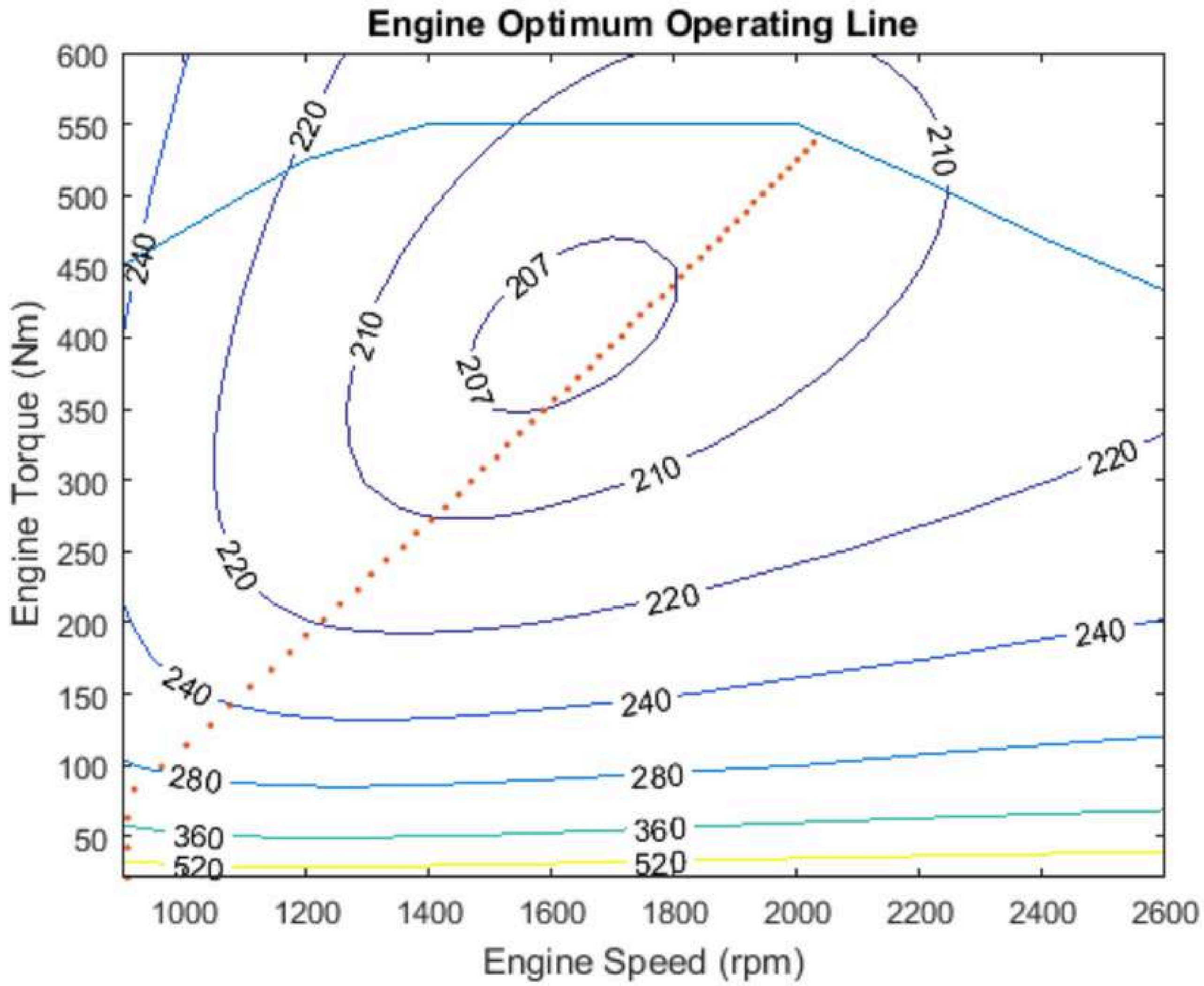
⬇

fuel-conscious operation

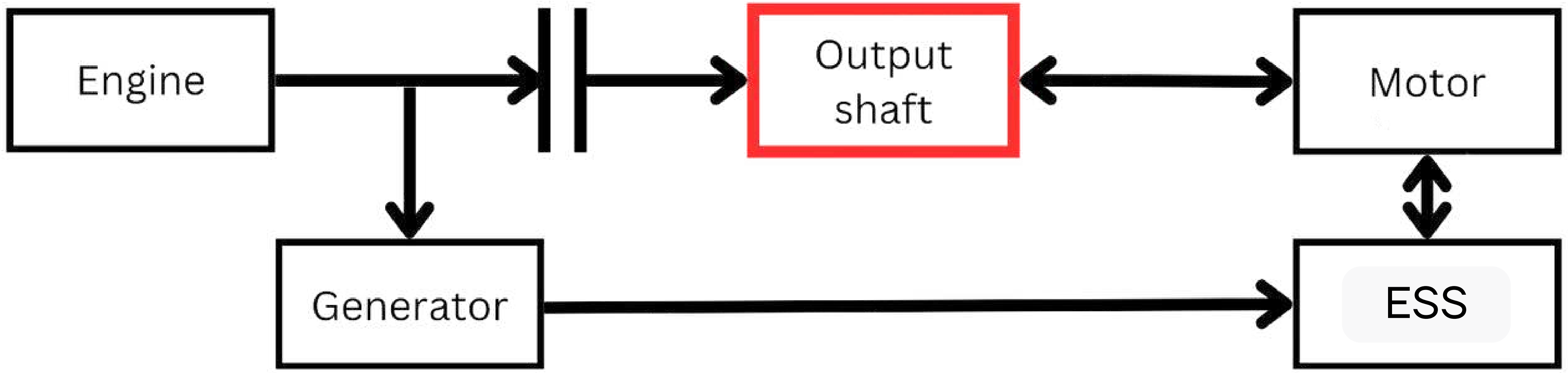
⬇

sustainable and economical





Series-Parallel Hybrid Architecture



Legend:

Clutch

Two Way Connections

One Way Connections

OBJECTIVES

the study aims to implement and investigate fuel-conscious operation in a simplified series-parallel hybrid drivetrain

Characterize fuel consumption behavior of the engine

Plot the Optimal Operation Line (**OOL**)

Integrate OOL data and test the series-parallel hybrid drivetrain

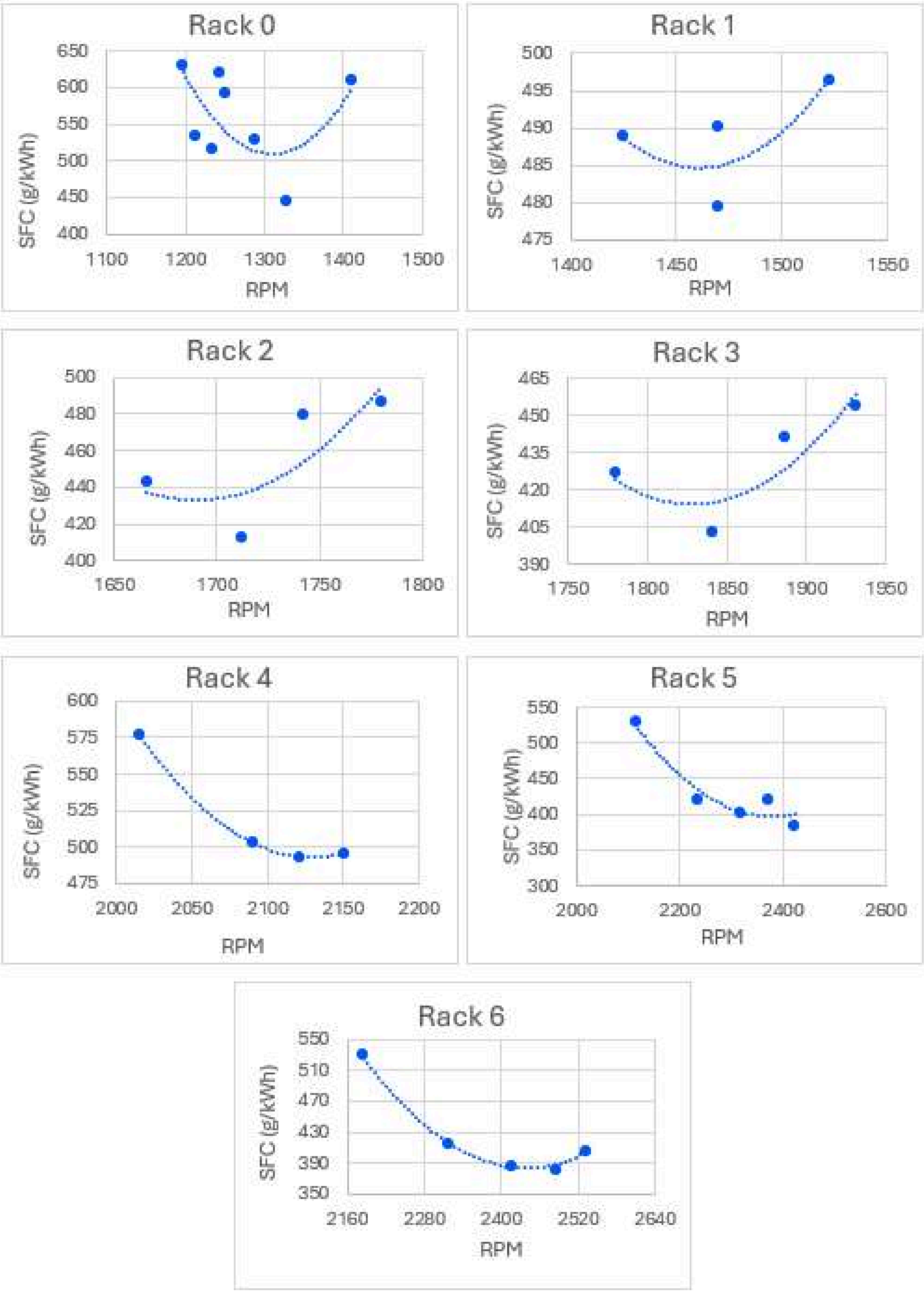
Investigate hybrid system behavior

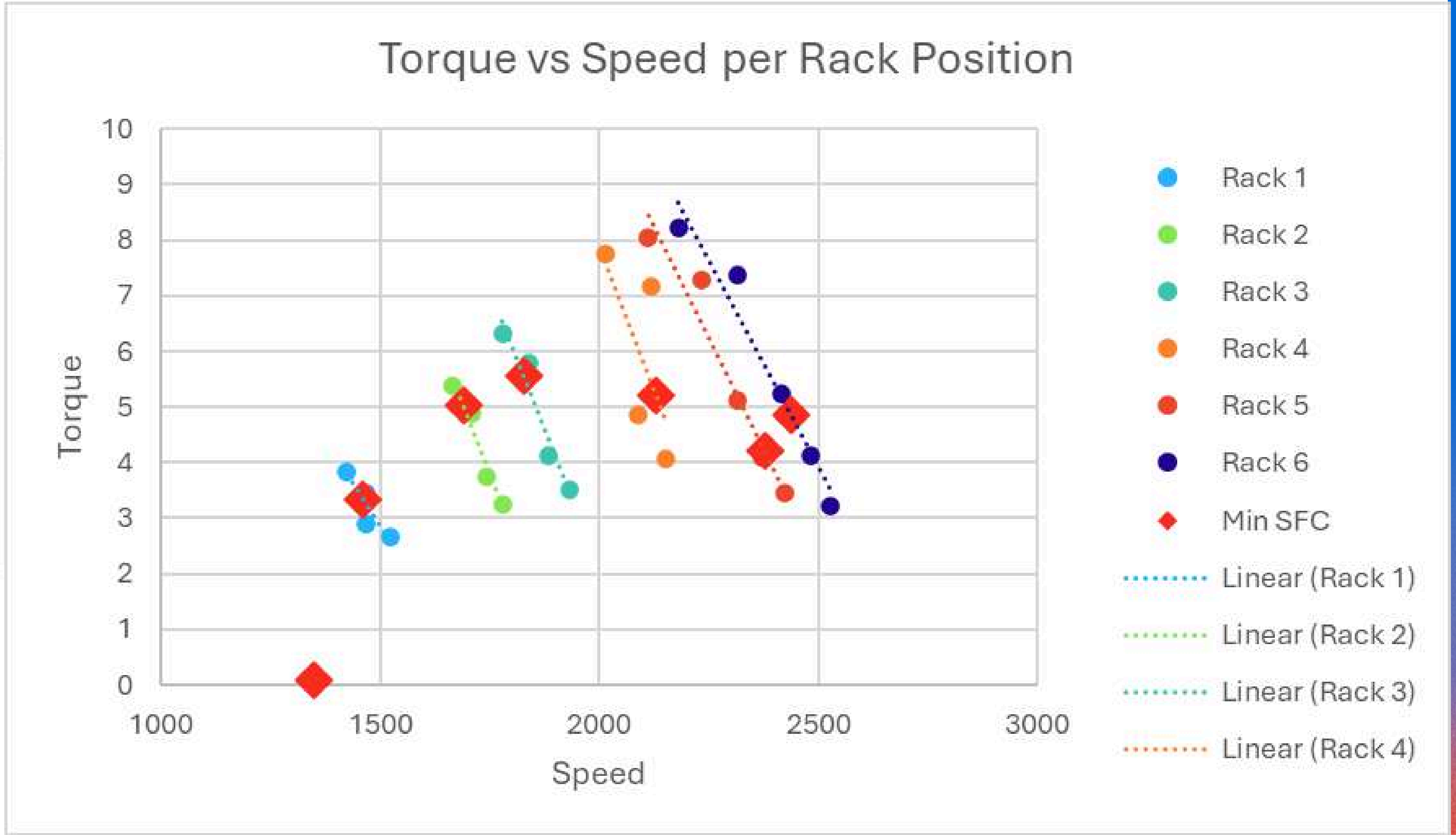
Engine Characterization

1. Set engine rack position and load, and run engine at steady state.
2. Record stable current and voltage values
3. Record fuel consumed and duration
4. Repeat for each rack (0 to 7) and each load (A to E)

Engine Characterization

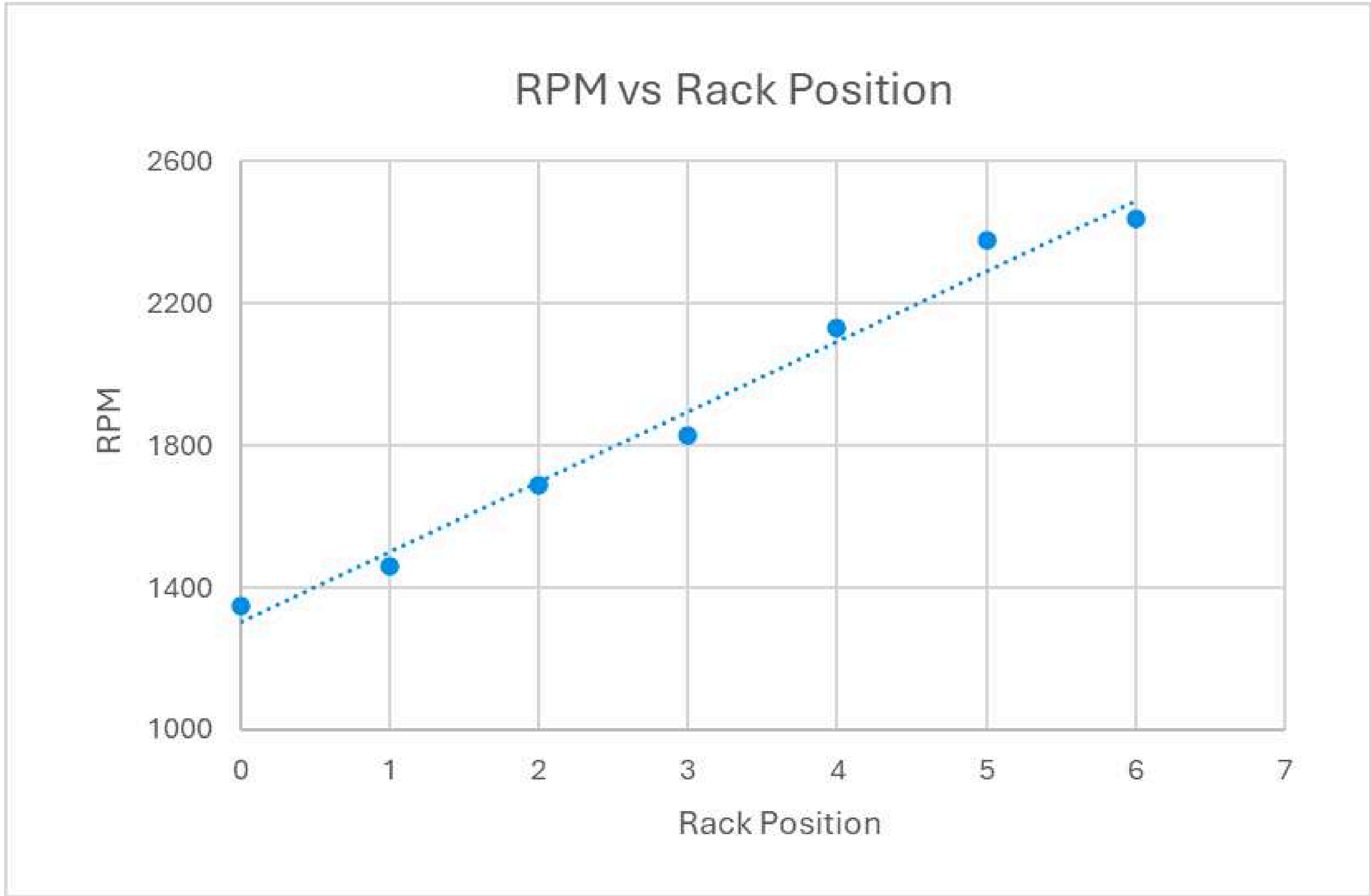
finding the OOL-set of optimal operating points





integrating the OOL
into the control system

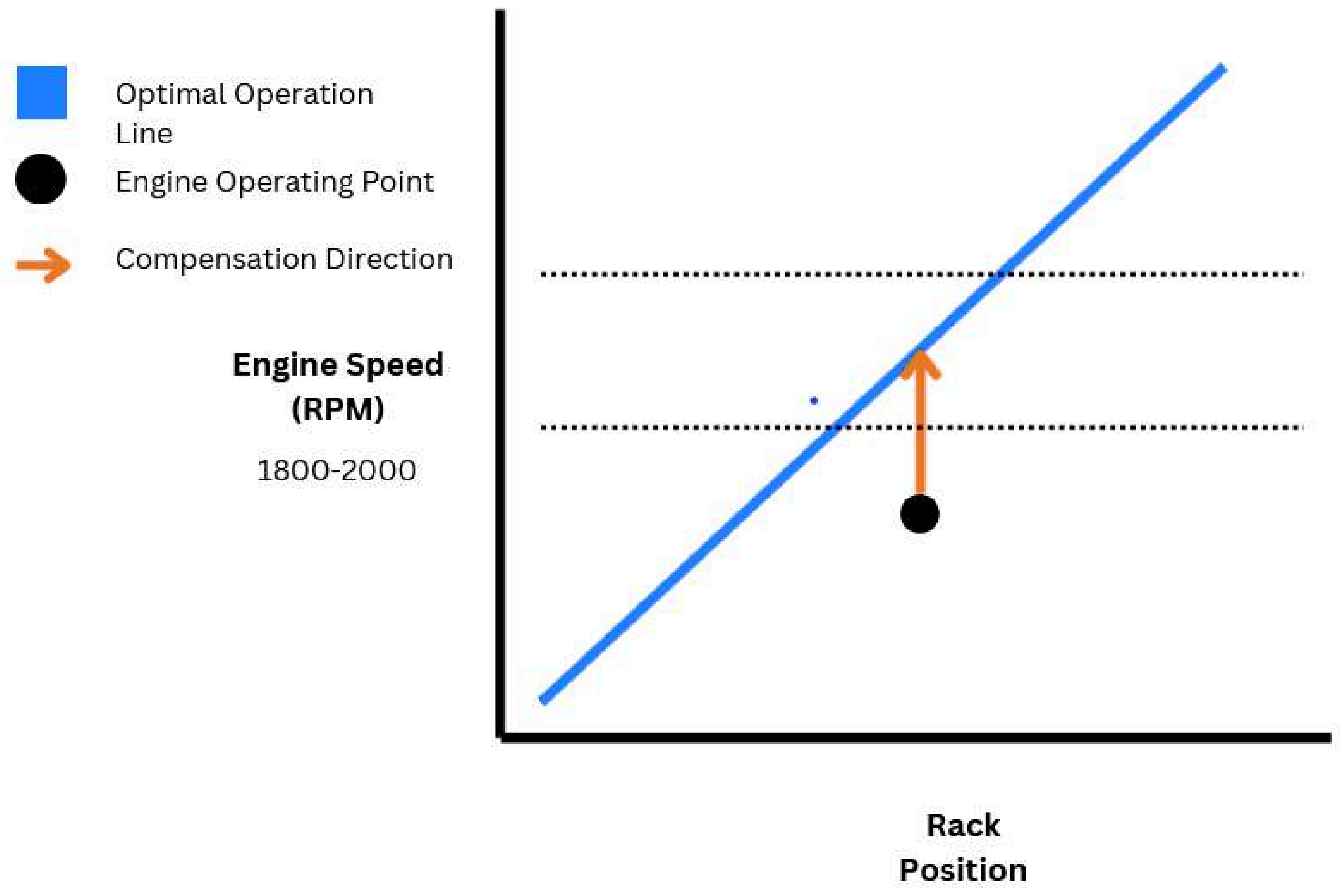
Engine Characterization

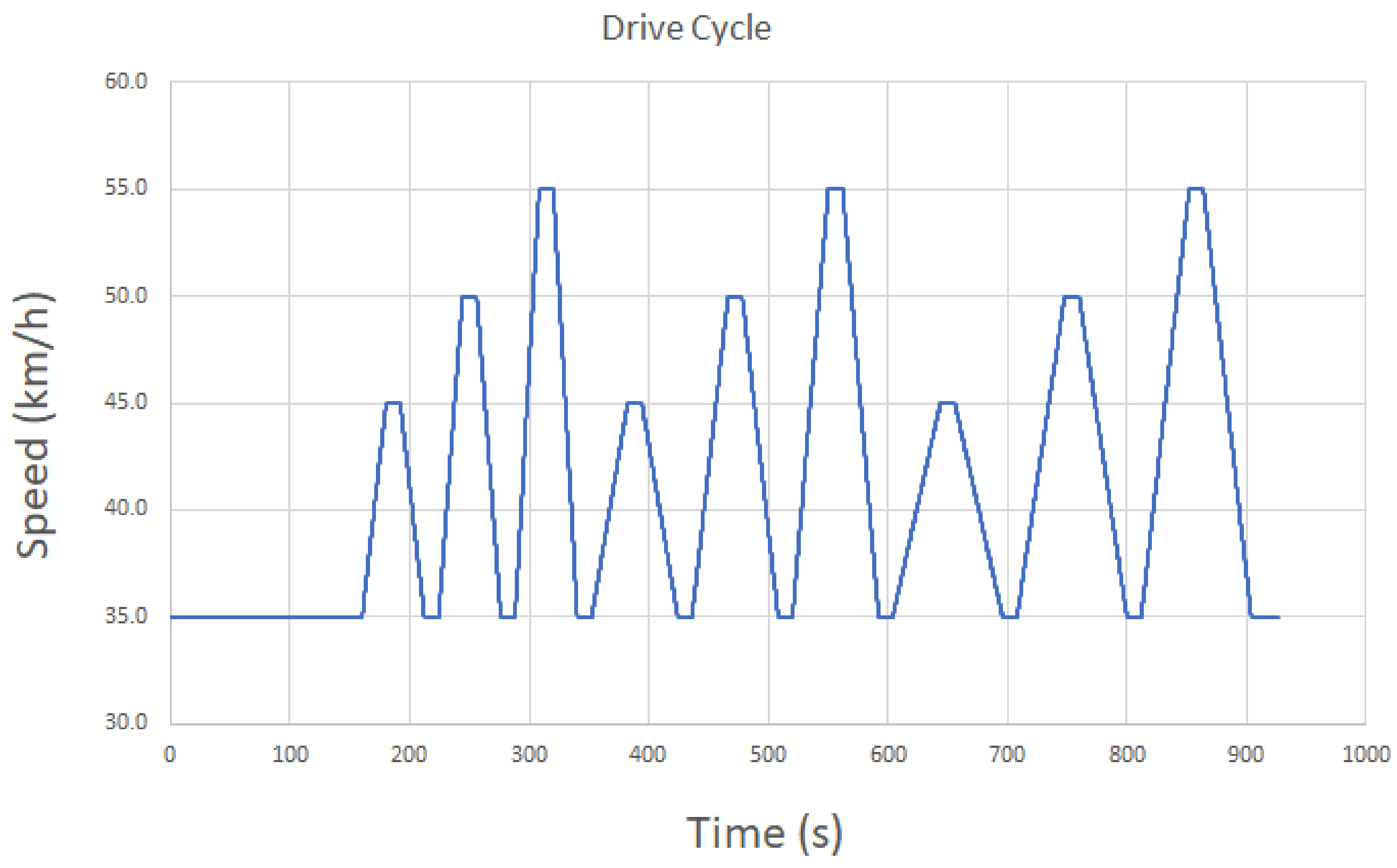


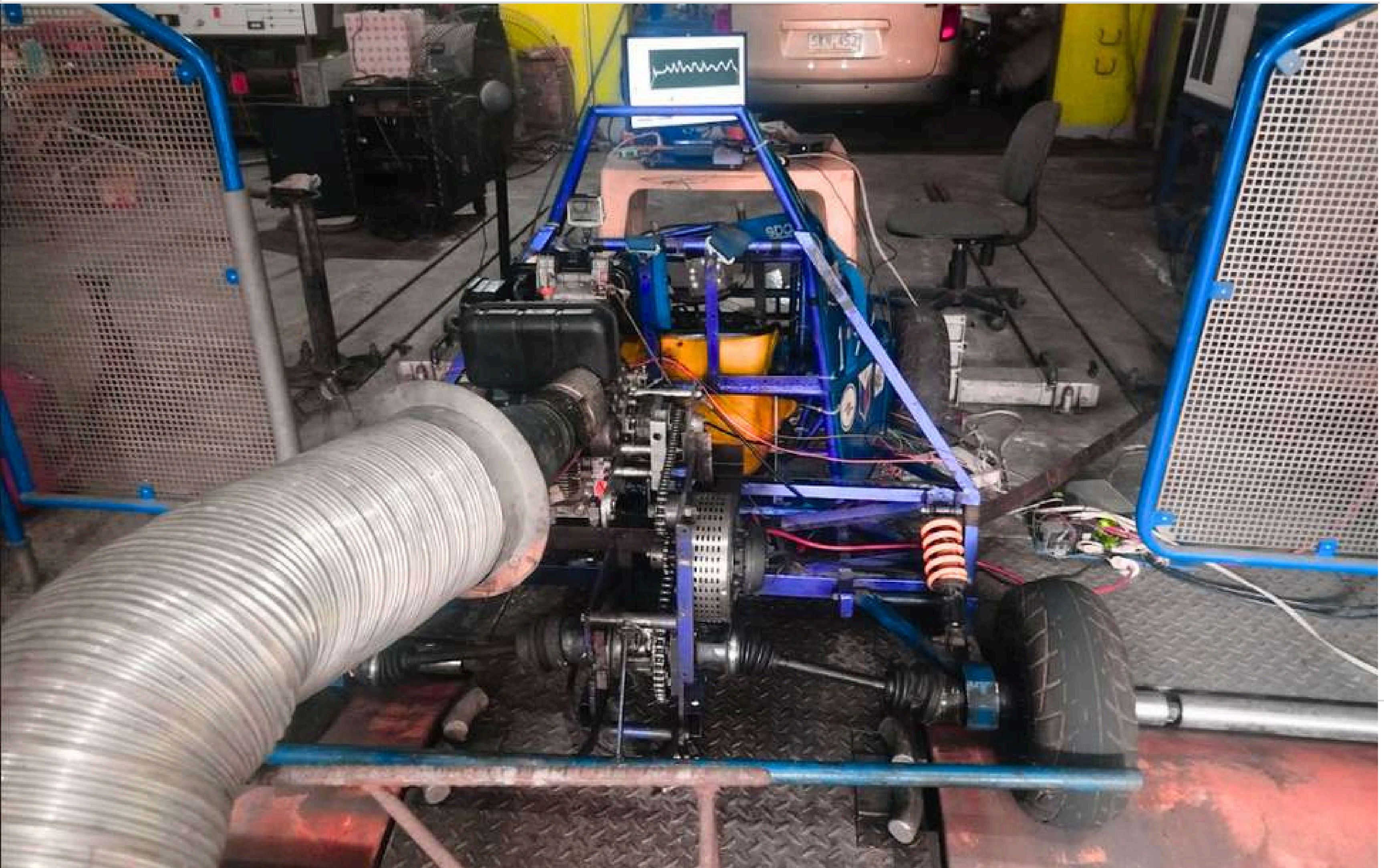
$$197.82x + 1303$$

integrating the OOL
into the control system

Control Strategy





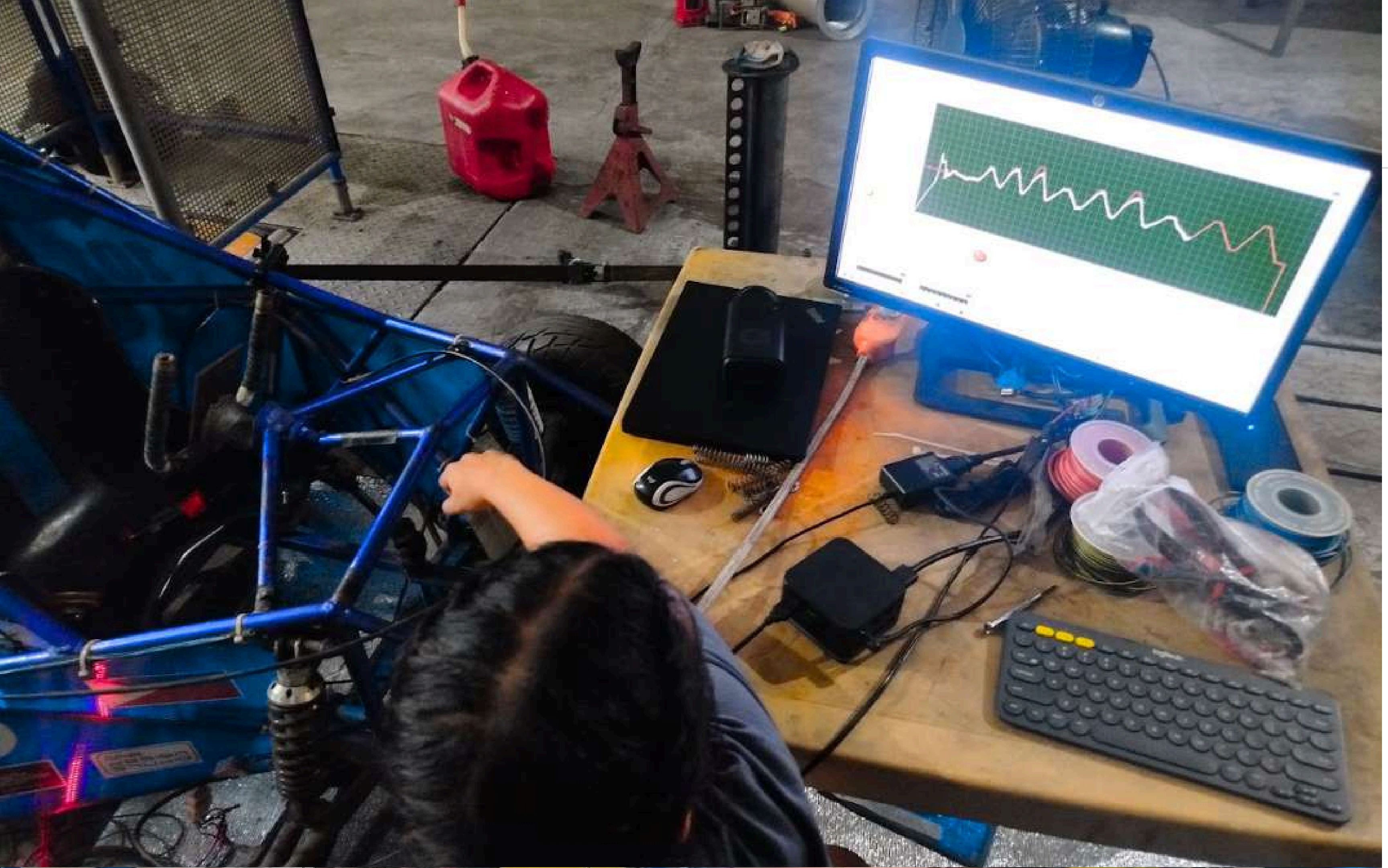


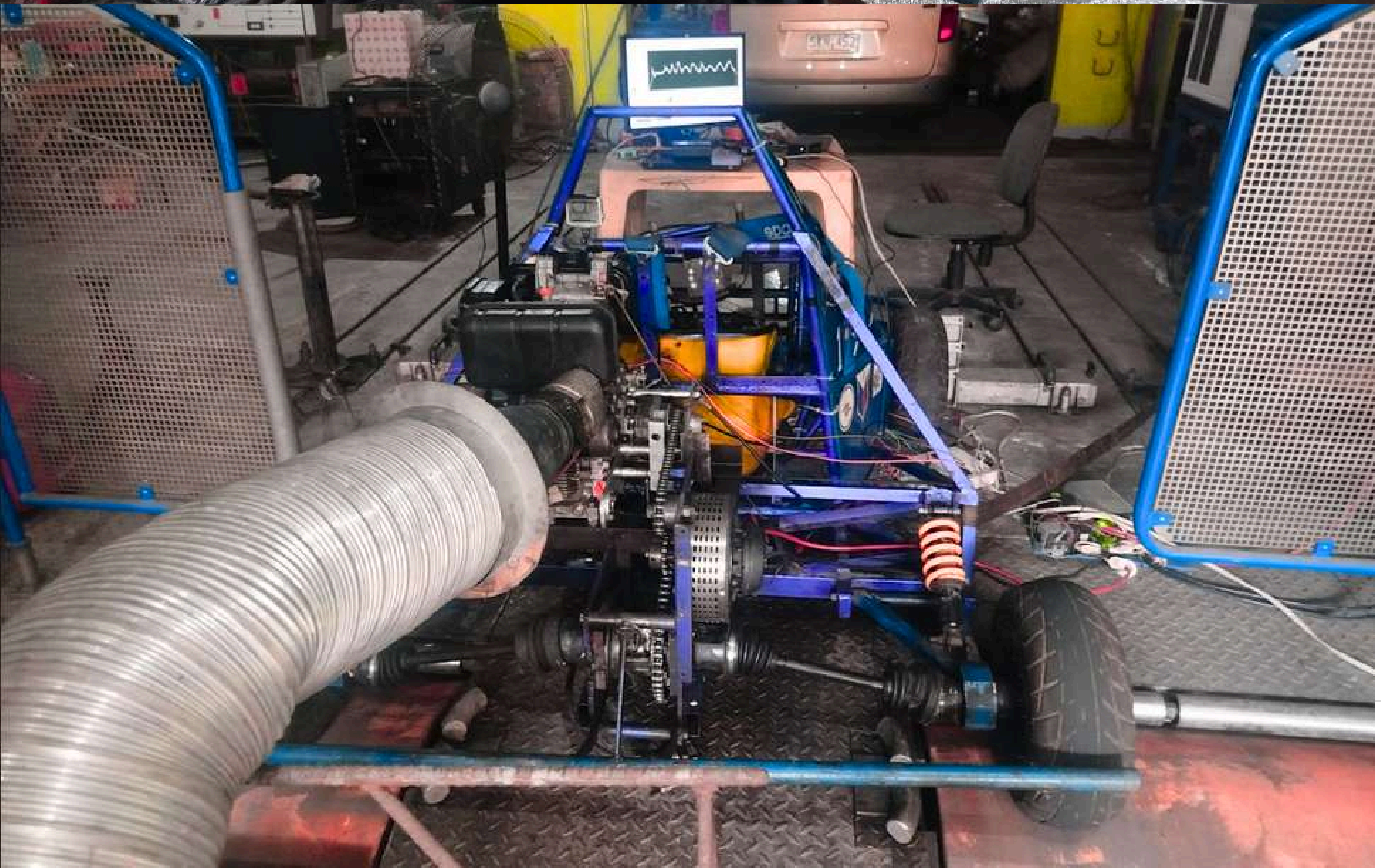
Drive Cycle Test

Strap the vehicle on a passive chassis dyno

Roller Specs:

- *Two 48-inch diameter rollers*
- *1360 Kg Combined Inertia*

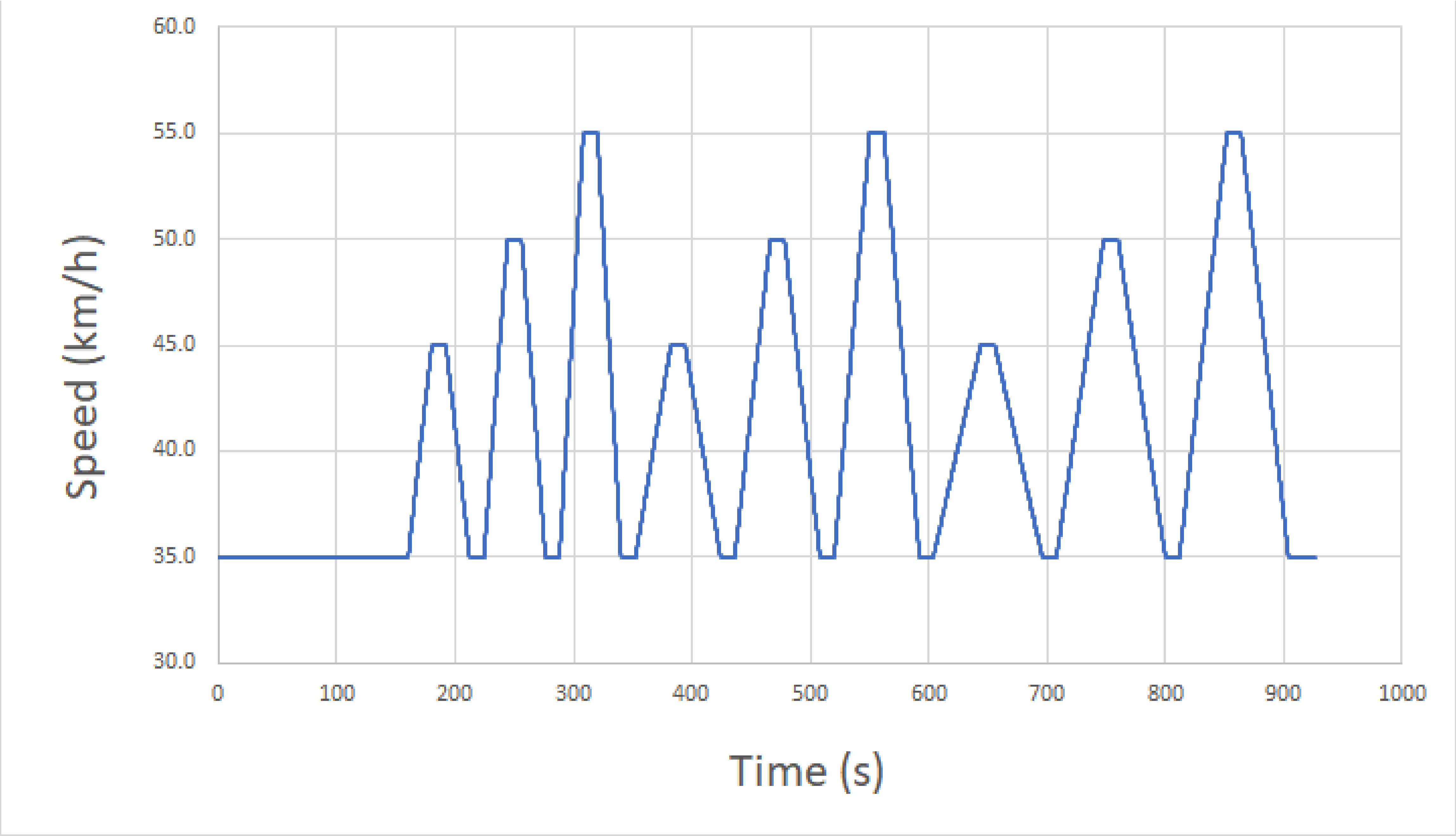




Drive Cycle Procedure

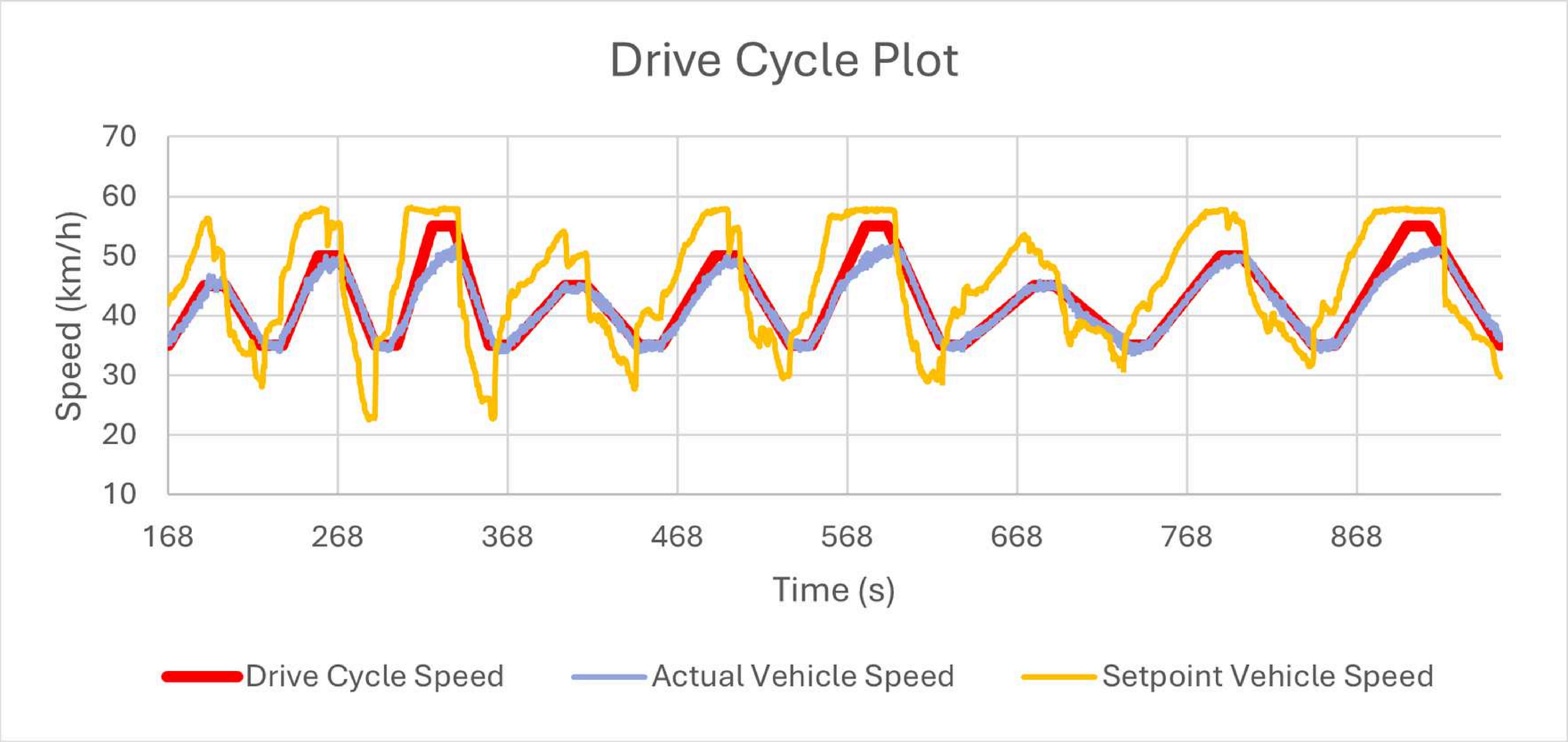
1. The hybrid system is run on motor-only: Engine Off - Clutch Disengaged
2. As vehicle speed approaches 35km/h: Engine On - Clutch engaged
3. Operator Follows the drive cycle along the way

Drive Cyle

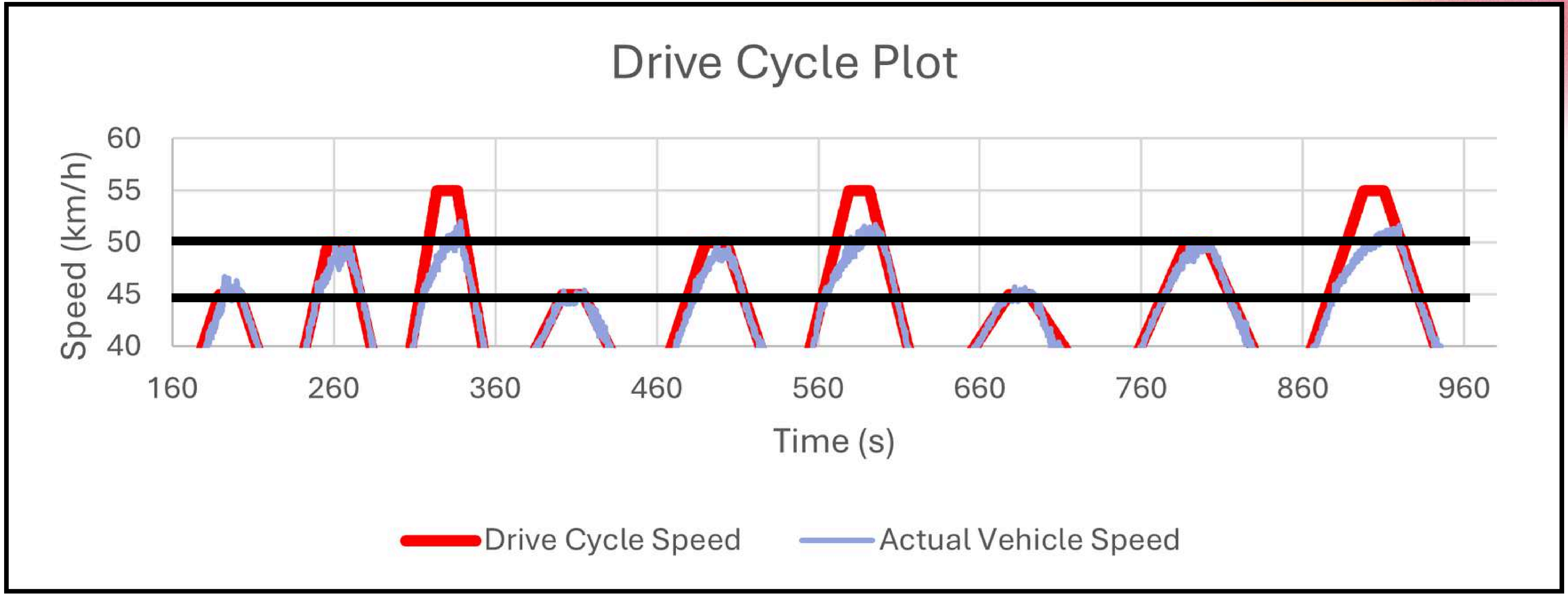


60.0
55.0
50.0
45.0
40.0
35.0
30.0
Speed (km/h)
0
100
200
300
400
500
600
700
800
900
1000
Time (s)

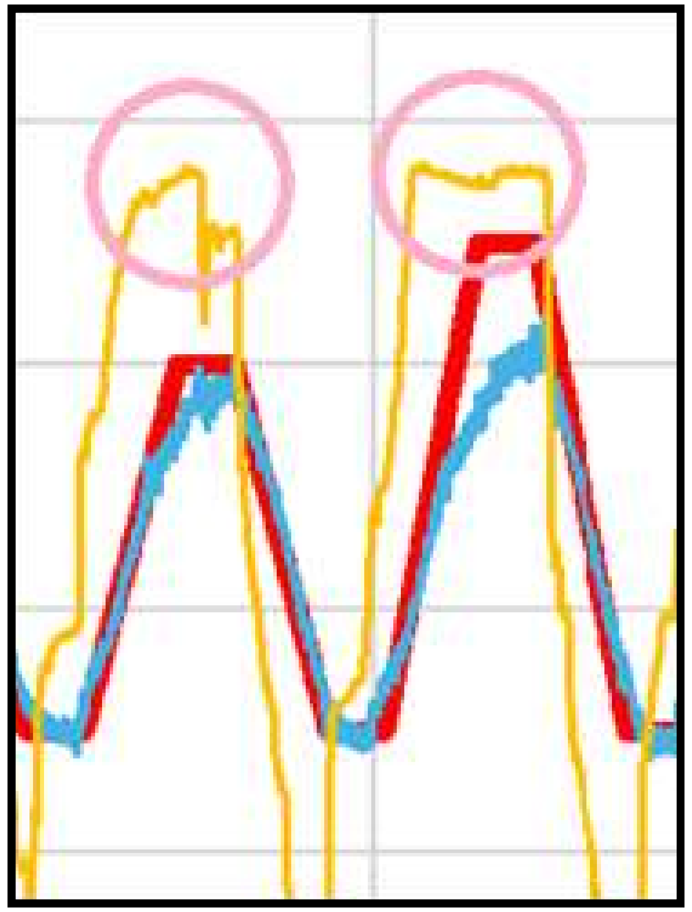
Drive Cycle Results



Drive Cycle Peaks

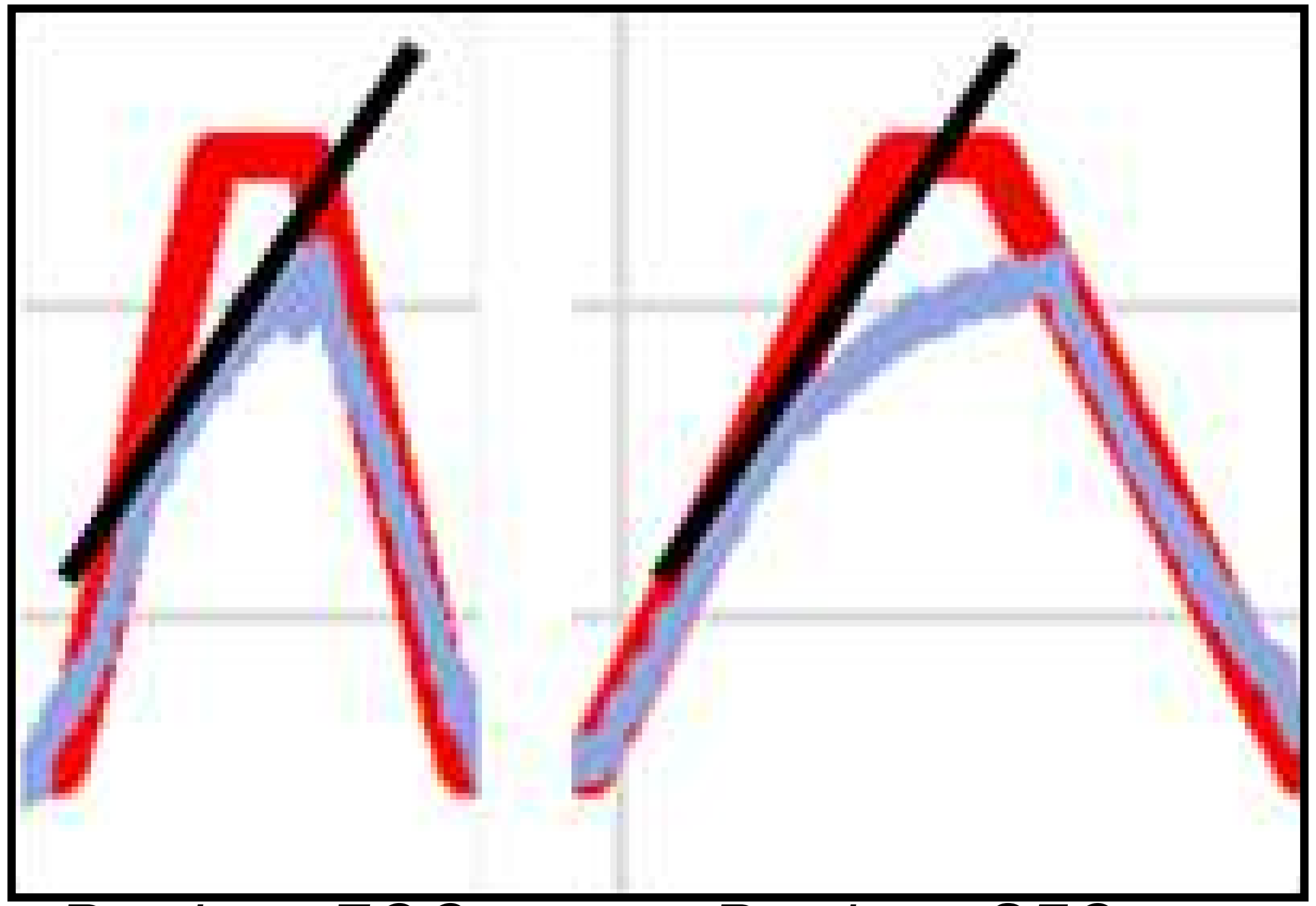


Drive Cycle Peaks



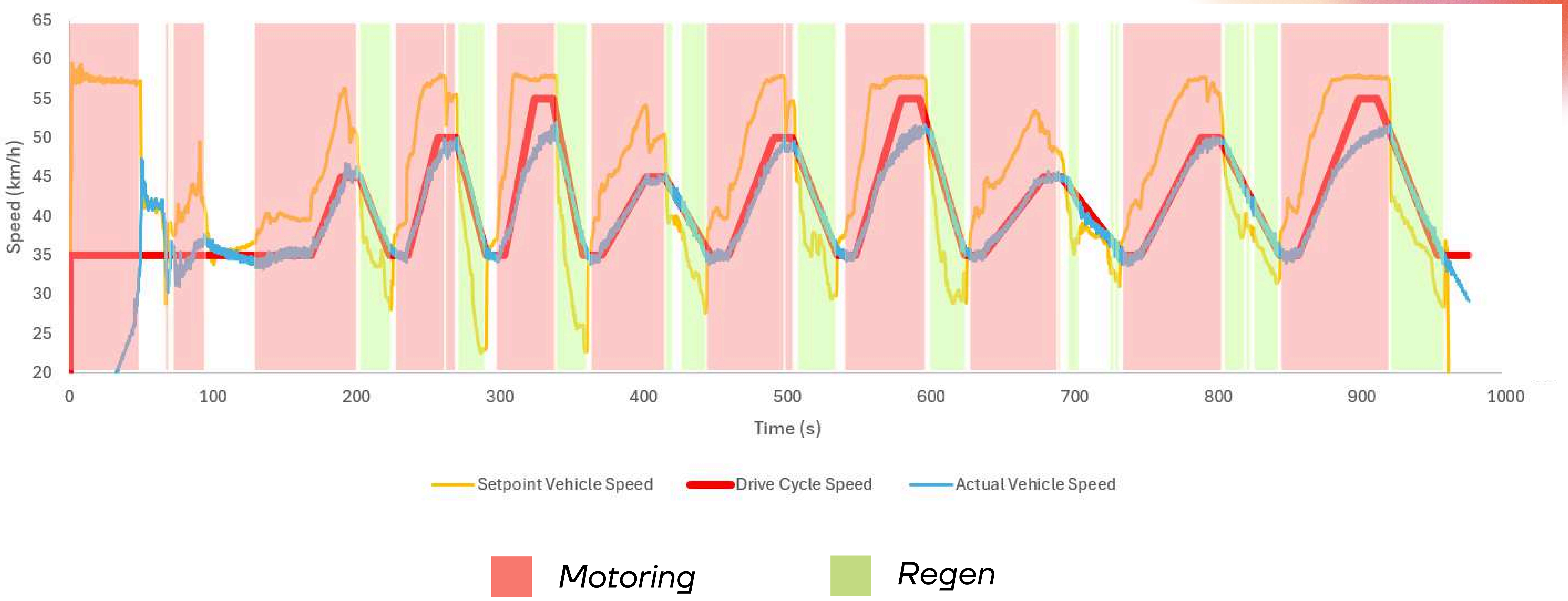
Setpoint Vehicle Speeds

Drive Cycle Peaks



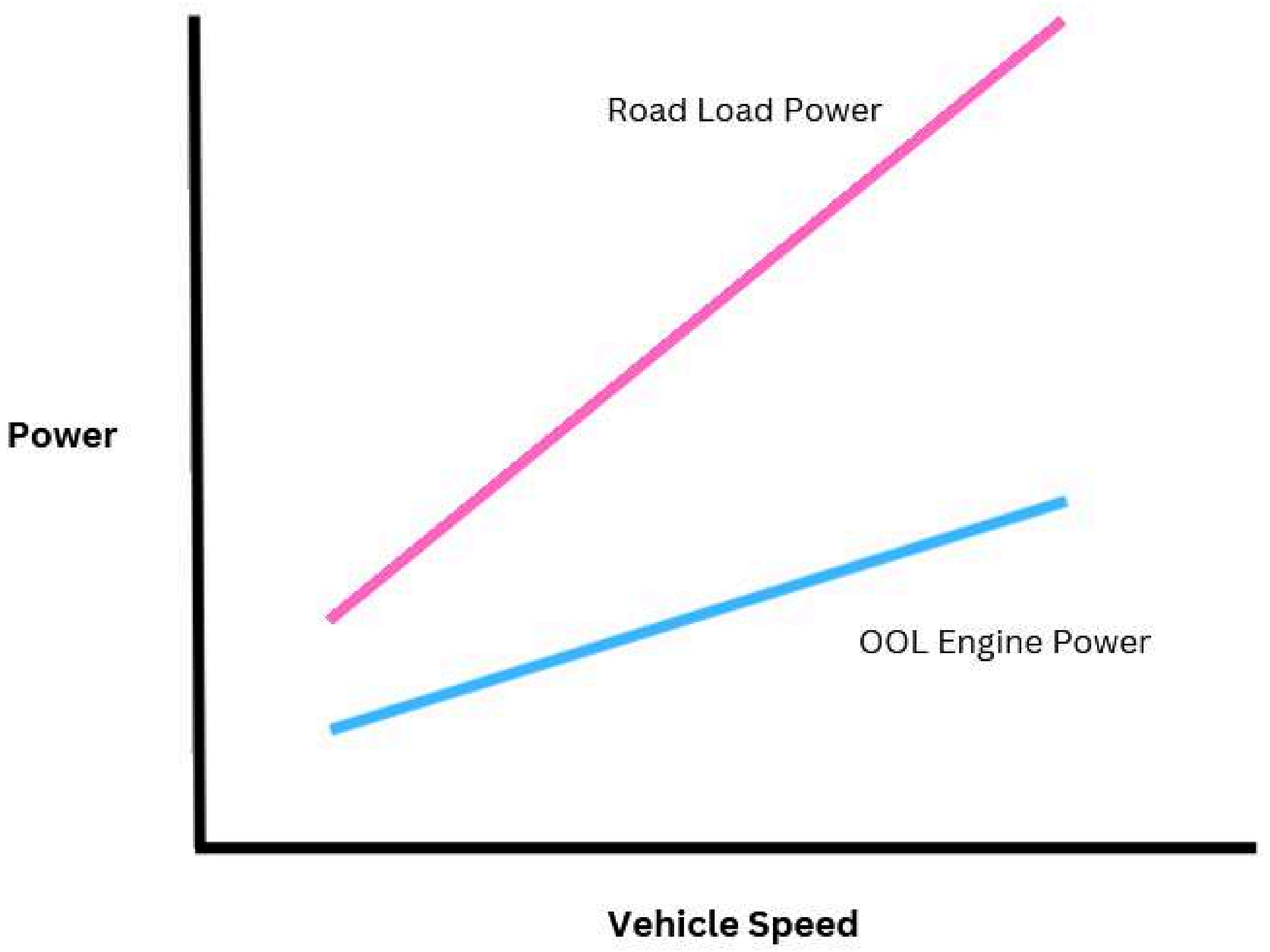
Peak at 300s   Peak at 850s

Drive Cycle Masked by Motor modes

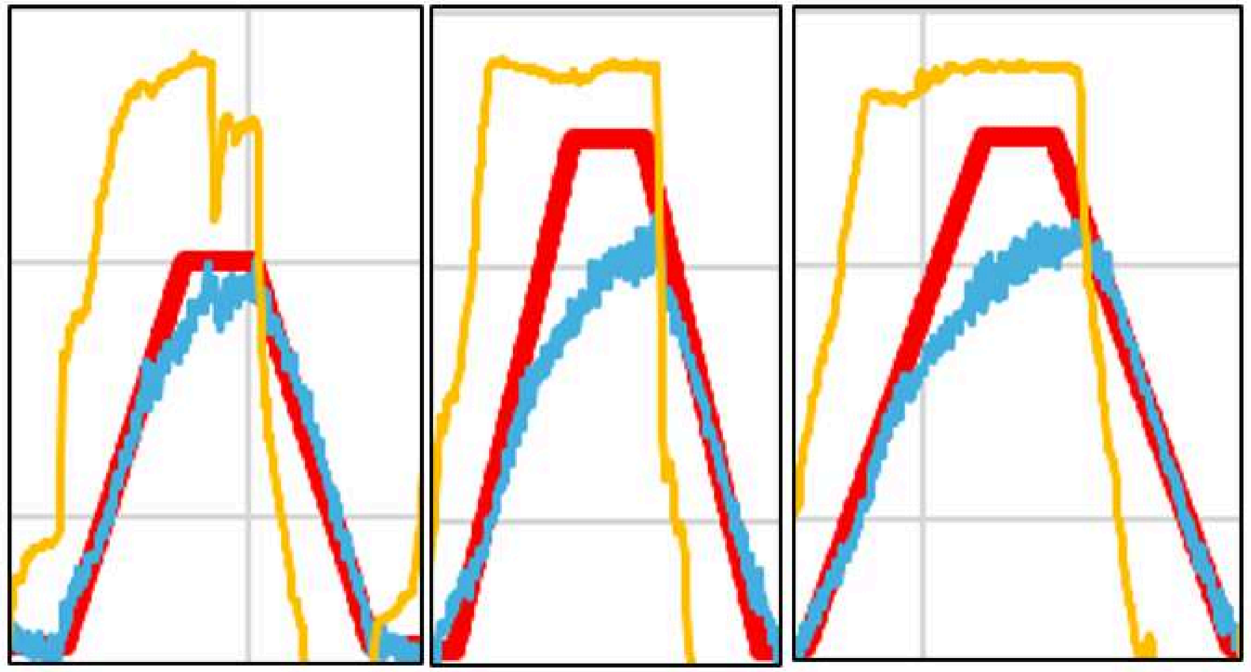


Drive Cycle by Motoring modes

Initial Velocity (km/h)	Final Velocity (km/h)	Duration (s)	Acceleration (km/h/s)	Percent Idle	Percent Motoring	Percent Regen
35	35	12	0	20.88%	71.39%	7.73%
45	45	12	0	3.89%	96.11%	0.00%
50	50	12	0	1.11%	98.89%	0.00%

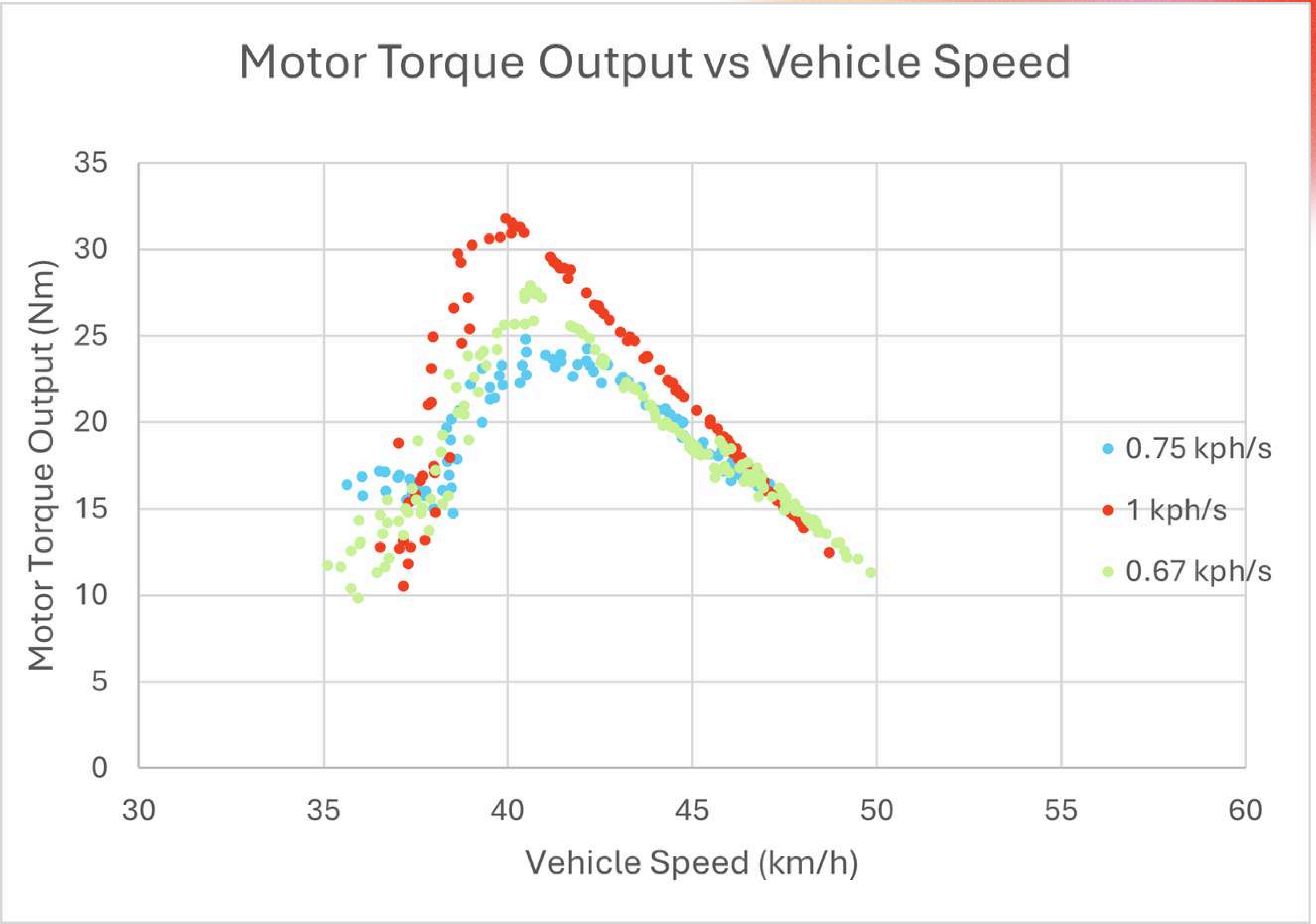


Torque Output of the Motor



0.75 kph/s | 1 kph/s | 0.67 kph/s

Segments of Highest Acceleration



CONCLUSION

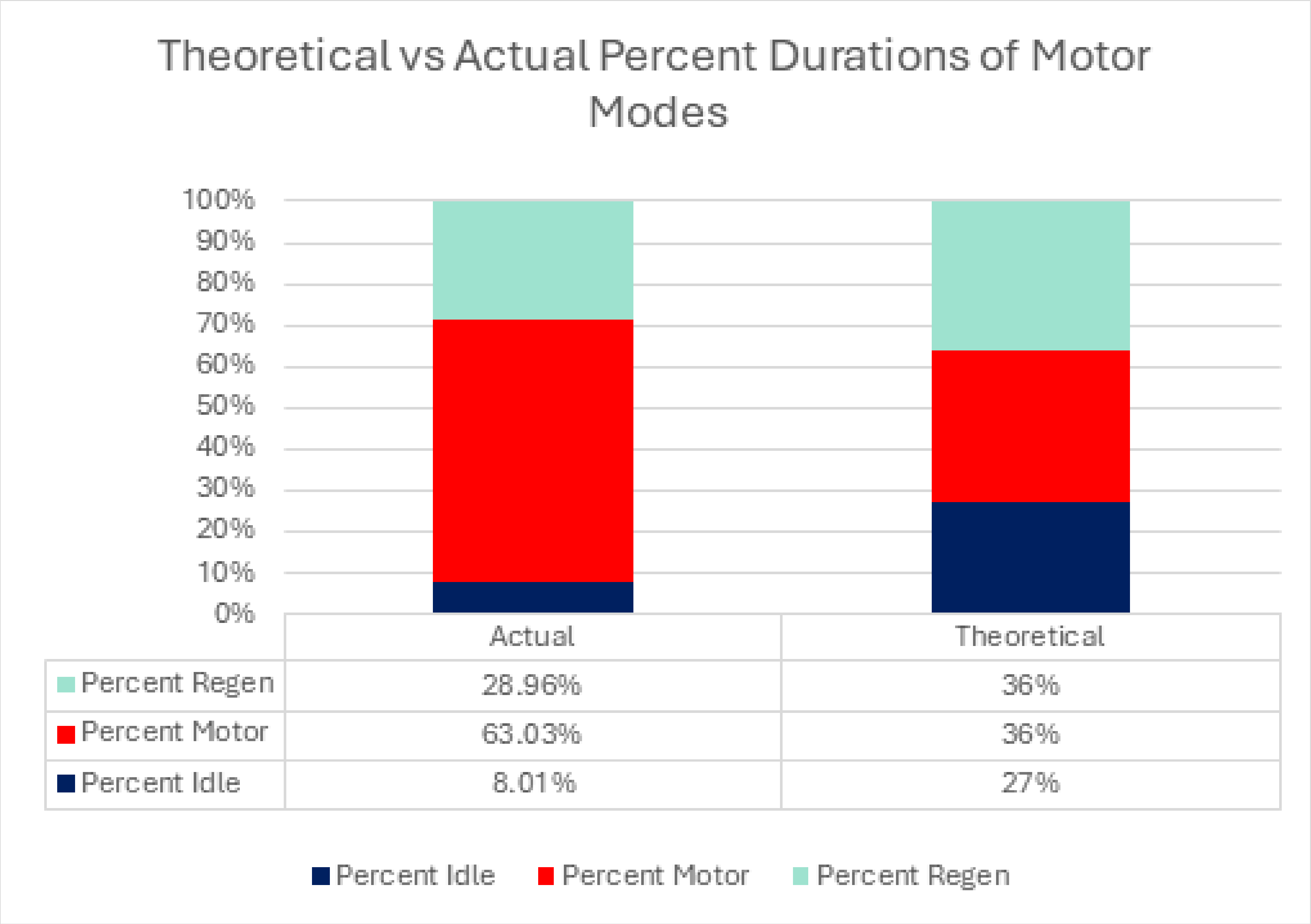
- *The engine characterization yielded engine speed values per rack position with the lowest specific fuel consumption.*
- *The system was able to successfully switch from motoring to regen mode based on vehicle load demands and the target speed.*
- *The system was observed to be able to align engine operation to the OOL at certain portions of the drive cycle, but only at low vehicle speeds.*

RECOMMENDATIONS

- *Sweep bigger part of engine operating envelope*
- *Perform a coast down test for accurate road load information*
- *Component sizing and controller tuning such that the developed drive cycle can be followed more thoroughly.*
- *Adjust drive cycle metrics for regen, longer dwells*
- *Consider state of charge of the ESS*
- *Consider a cost and feasibility analysis for future studies*
- *Adjust the starting rack position to 1*

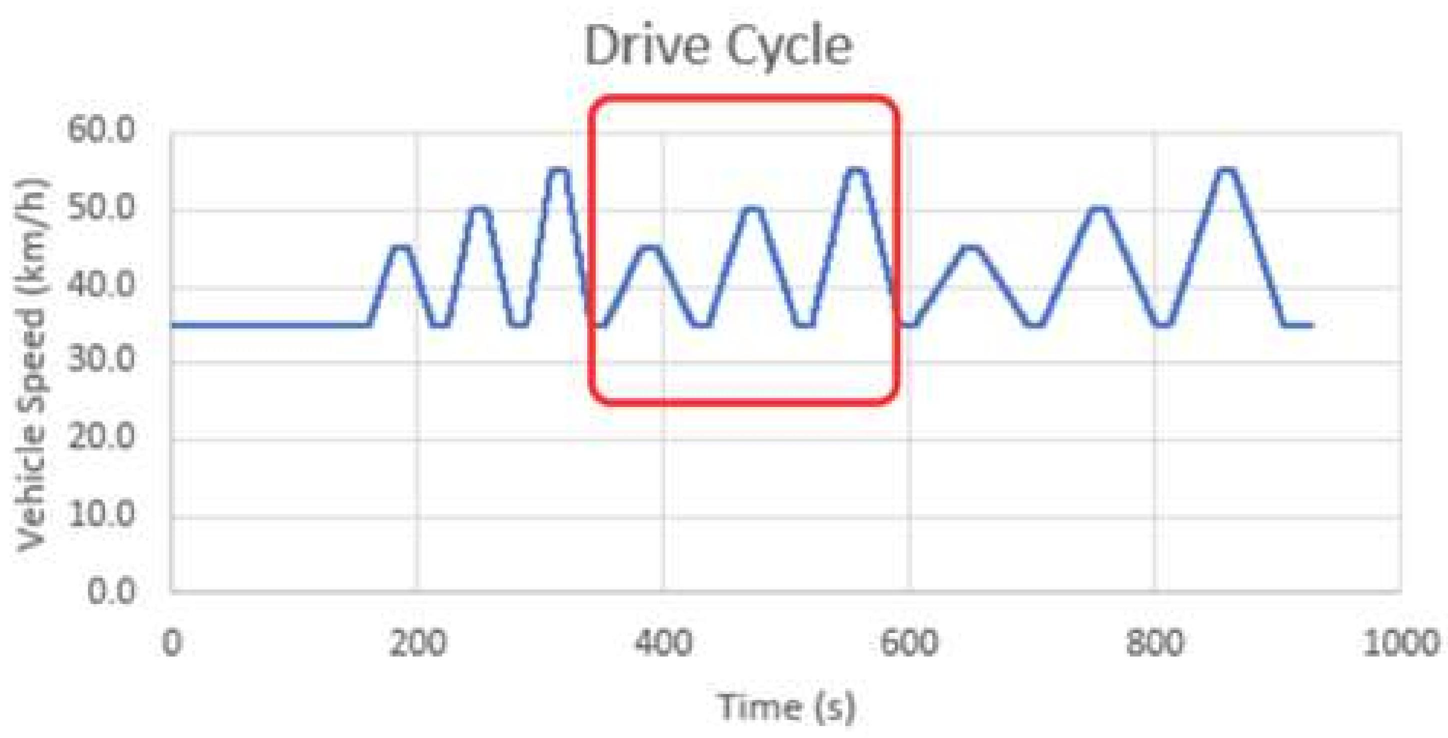

THANK YOU!

Durations of Motor Modes



	Actual	Theoretical
Percent Regen	28.96%	36%
Percent Motor	63.03%	36%
Percent Idle	8.01%	27%

Torque Output of the Motor (Mid Drive Cycle Portion)



Mid Drive Cycle Portions

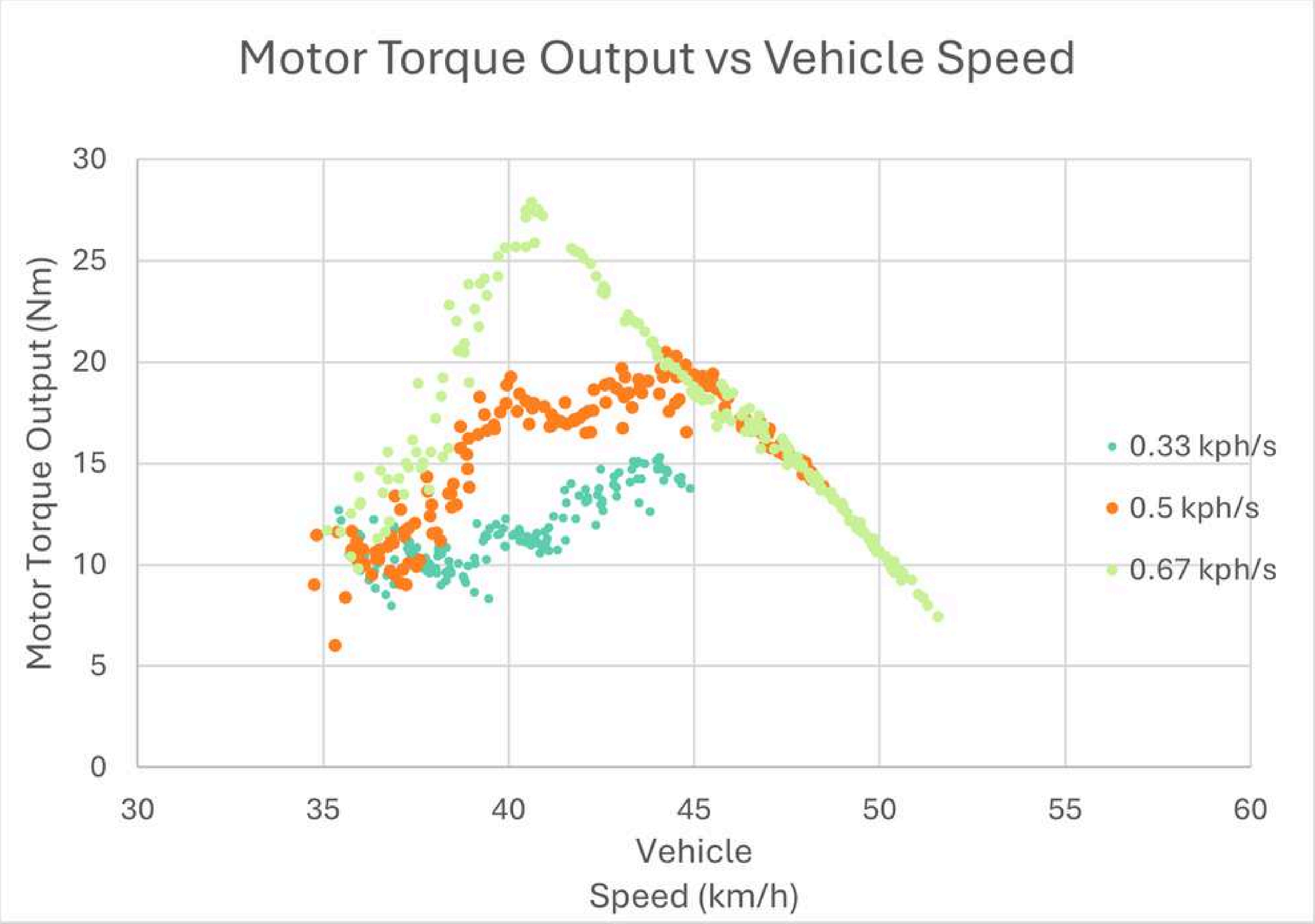
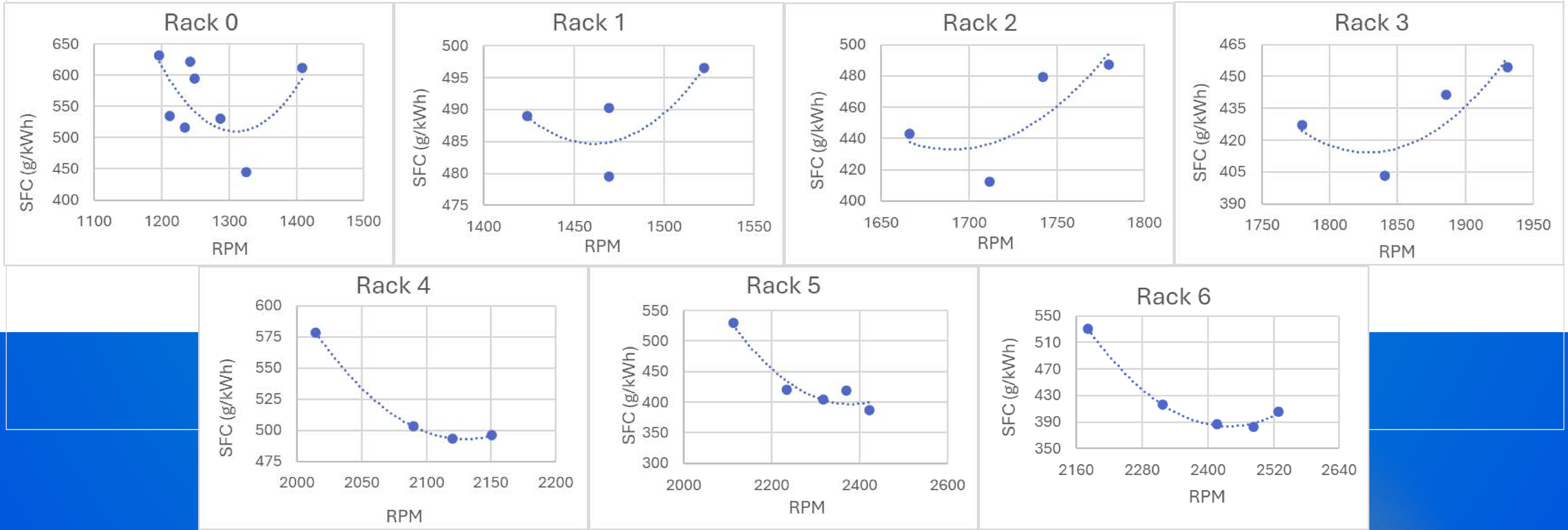
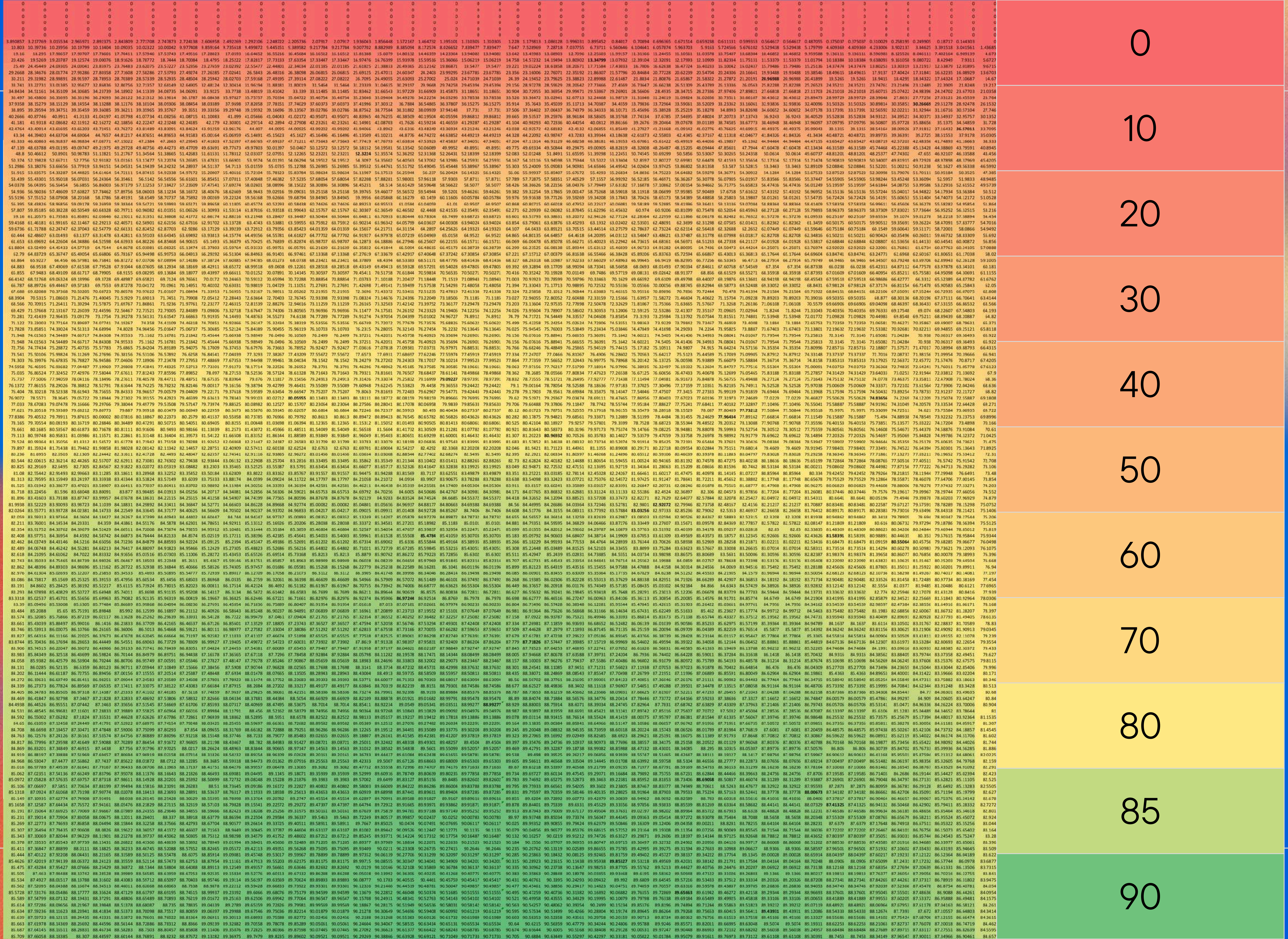


Table 4.1. Equation 4.2 Coefficients, R-squared, and Optimum RPM Values per Rack Position

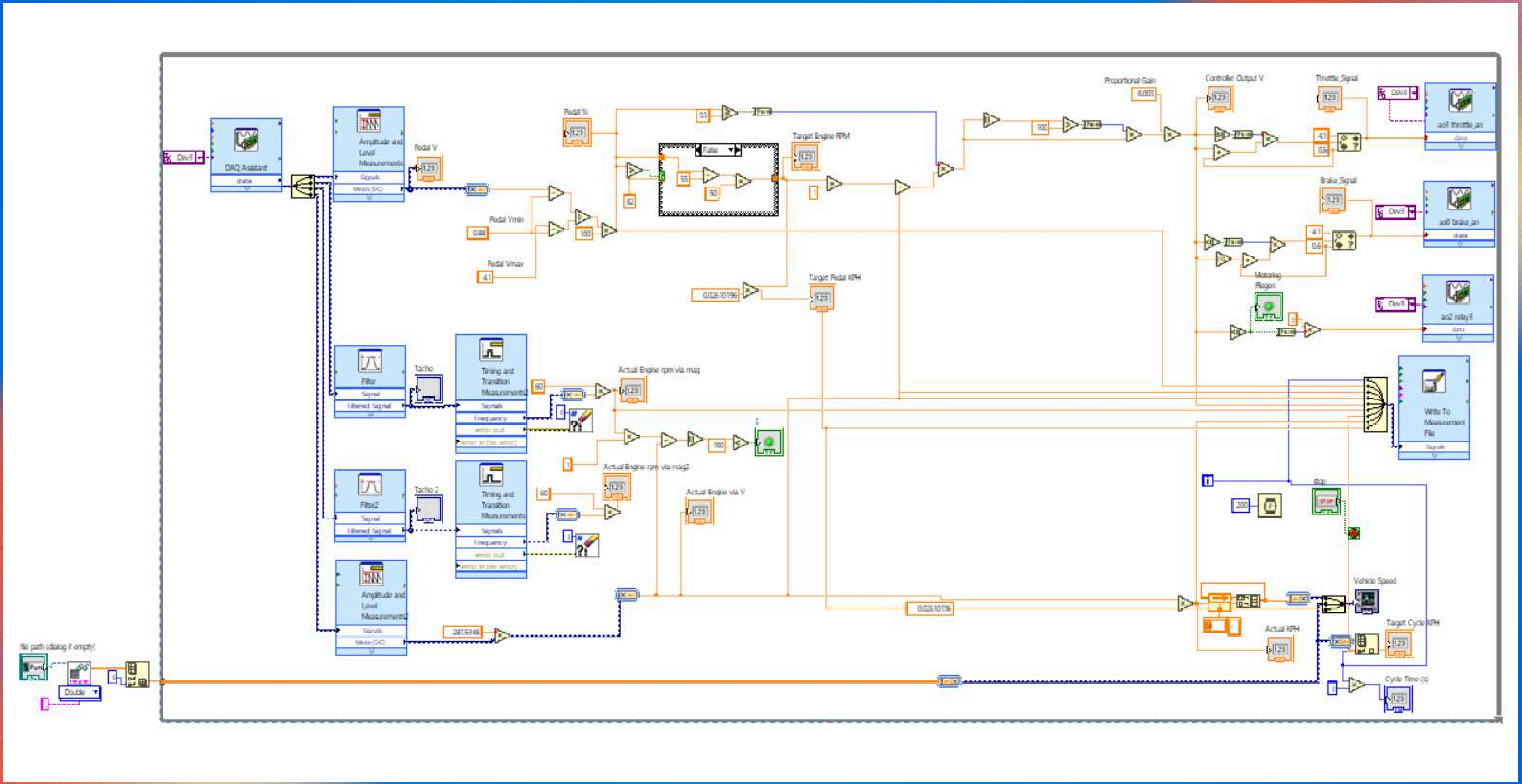
	Rack 0	**Rack 1**	**Rack 2**	**Rack 3**	**Rack 4**	**Rack 5**	**Rack 6**
A	0.00871	0.00313	0.00768	0.00421	0.00641	0.00182	0.00222
B	-22.822	-9.1509	-25.962	-15.427	-27.334	-8.6721	-10.859
C	15455.4	7168.46	22371.1	14517.1	29598.6	10710.8	13619.4
R^2	0.375	0.609	0.625	0.767	0.999	0.927	0.997
Optimum RPM	1309.77	1460.79	1690.03	1828.29	2129.67	2378.65	2437.85



Agni Efficiency Map



Controller Schematic



Engine Test Data

			raw data									
	[A/B/C]	[g]	[s]	[V]	[A]	[g/s]	[kW]	[rpm]	[%]	[kW]	[Nm]	[kg/kWh]
rack	load	Fuel	Time	oltage-Mo	urrent-Mo	Fuel Rate	Power-Motor	rpm-Engine	iciency-Mo	ower-Engir	orque-Engir	ave SFC
0	bc	10	187.5	17	11	0.0533333	0.187	1287.467	51.6153	0.362296	2.687191	529.9539
0	b	10	195.7	17.5	7.7	0.0510986	0.13475	1325.333	33.7738	0.398978	2.874717	461.0657
0	ab	10	182.8	16.3	14.7	0.0547046	0.23961	1234.453	62.845	0.381271	2.949381	516.5259
0	bc	10	200.53	15.5	10	0.0498679	0.155	1173.867	45.87871	0.337847	2.748357	531.3769
0	ab	10	189.48	15.3	13.2	0.052776	0.20196	1158.72	56.74522	0.355907	2.933114	533.8301
0	b	10	175.63	16	6.9	0.0569379	0.1104	1211.733	27.2966	0.404446	3.187314	506.8078
0	abc	10	190.32	14.5	15.6	0.0525431	0.2262	1098.133	62.80103	0.360185	3.132147	525.1607
0	abc	10	164.32	16	17.8	0.0608569	0.2848	1211.733	69.4899	0.409844	3.229852	534.5567
0.5	bc	10	165.3	19.4	14.6	0.0604961	0.28324	1469.227	63.7591	0.444235	2.88732	490.2496
0.5	b	10	173.59	20.1	11	0.057607	0.2211	1522.24	52.3224	0.422572	2.650876	490.7685
0.5	ab	10	143.92	19.4	20.9	0.069483	0.40546	1469.227	76.107	0.53275	3.462629	469.5242
0.5	abc	10	128.53	18.8	24.4	0.0778028	0.45872	1423.787	80.0596	0.572973	3.842914	488.8366
1	bc	10	112.83	23	23.5	0.0886289	0.5405	1741.867	79.0923	0.683379	3.746433	466.892
1	b	10	121.65	23.5	18.9	0.082203	0.44415	1779.733	73.1185	0.607439	3.259259	487.1784
1	ab	10	99.4	22.6	33.2	0.1006036	0.75032	1711.573	85.4784	0.877789	4.897405	412.5969
1	abc	10	86.32	22	37.2	0.115848	0.8184	1666.133	86.9724	0.940988	5.393191	443.2073
1.5	bc	10	100.1	24.9	26.5	0.0999001	0.65985	1885.76	80.9693	0.814939	4.126766	441.3098
1.5	b	10	111.96	25.5	21	0.0893176	0.5355	1931.2	75.6665	0.707711	3.499451	454.3429
1.5	ab	10	79.94	24.3	40.3	0.1250938	0.97929	1840.32	87.7183	1.116403	5.792942	403.3827
1.5	abc	10	71.4	23.5	44.7	0.140056	1.05045	1779.733	88.9928	1.180376	6.333401	427.1533
2	ac	10	67.5	27.6	31.9	0.1481481	0.88044	2090.24	83.0326	1.060355	4.844248	502.9764
2	a	10	79.1	28.4	25.2	0.1264223	0.71568	2150.827	77.9643	0.917959	4.075577	495.7959
2	ab	10	45.88	28	50.4	0.2179599	1.4112	2120.533	88.6906	1.591149	7.165347	493.1376
2	abc	10	38.05	26.6	55.3	0.2628121	1.47098	2014.507	89.8533	1.637091	7.760245	577.9298
2.5	c	10	106.09	32	8.3	0.0942596	0.2656	2423.467	30.2667	0.877532	3.45778	386.6919
2.5	bc	10	71.53	30.6	33.2	0.1398015	1.01592	2317.44	81.5839	1.245246	5.131188	404.1655
2.5	b	10	84.04	31.3	24.4	0.118991	0.76372	2370.453	74.8366	1.020517	4.111119	419.7554
2.5	ab	10	50.24	29.5	50.8	0.1990446	1.4986	2234.133	88.0067	1.702825	7.278339	420.8069
2.5	abc	10	38.16	27.9	57.2	0.2620545	1.59588	2112.96	89.6566	1.779992	8.044482	530.0004
3	c	10	104.48	33.4	9.3	0.0957121	0.31062	2529.493	36.5701	0.849382	3.206573	405.6636
3	bc	10	70.32	31.9	33.4	0.1422071	1.06546	2415.893	80.5506	1.322721	5.228318	387.0395
3	b	10	87.63	32.8	23.8	0.1141162	0.78064	2484.053	72.7391	1.073205	4.125659	382.7955
3	ab	10	48.2	30.6	51.2	0.2074689	1.56672	2317.44	87.4132	1.792315	7.385455	416.7169
3	abc	10	36.11	28.8	58.4	0.2769316	1.68192	2181.12	89.4393	1.880516	8.233202	530.1491

Motivation for Hybridizing

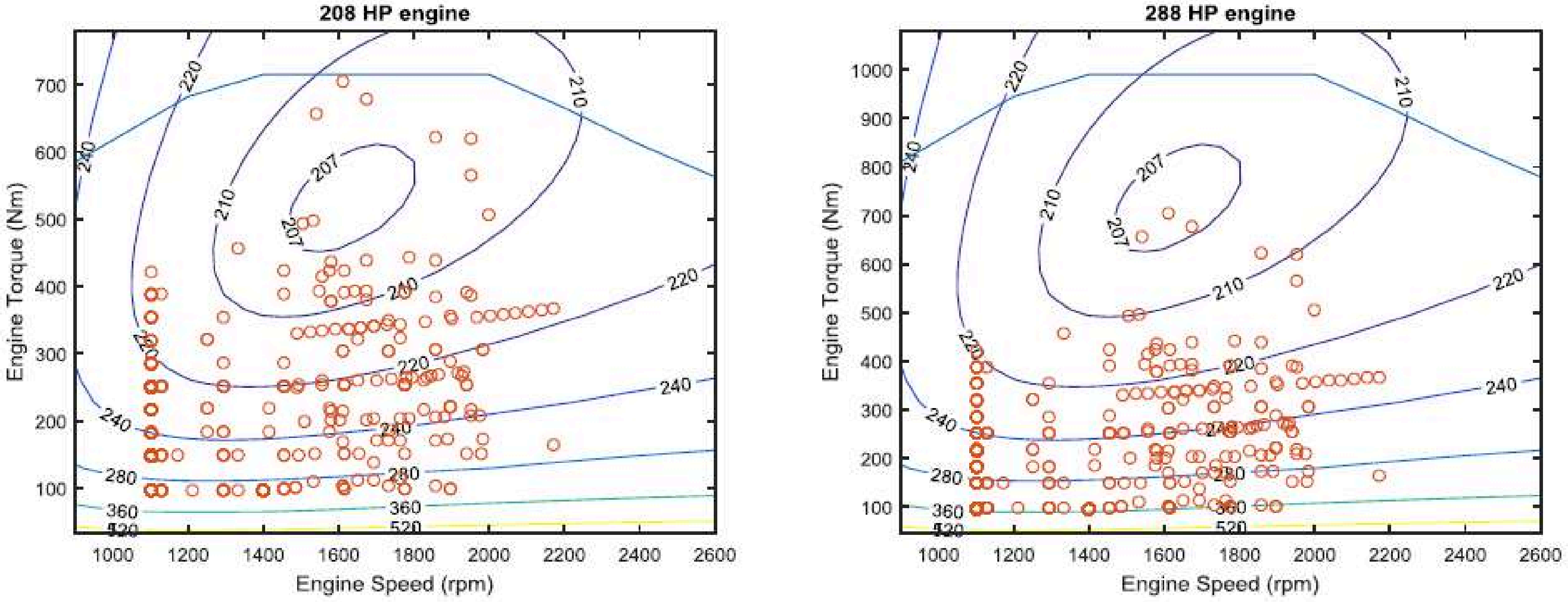


Figure 8.1. Effect of Reducing Engine Size for Efficient Utilization

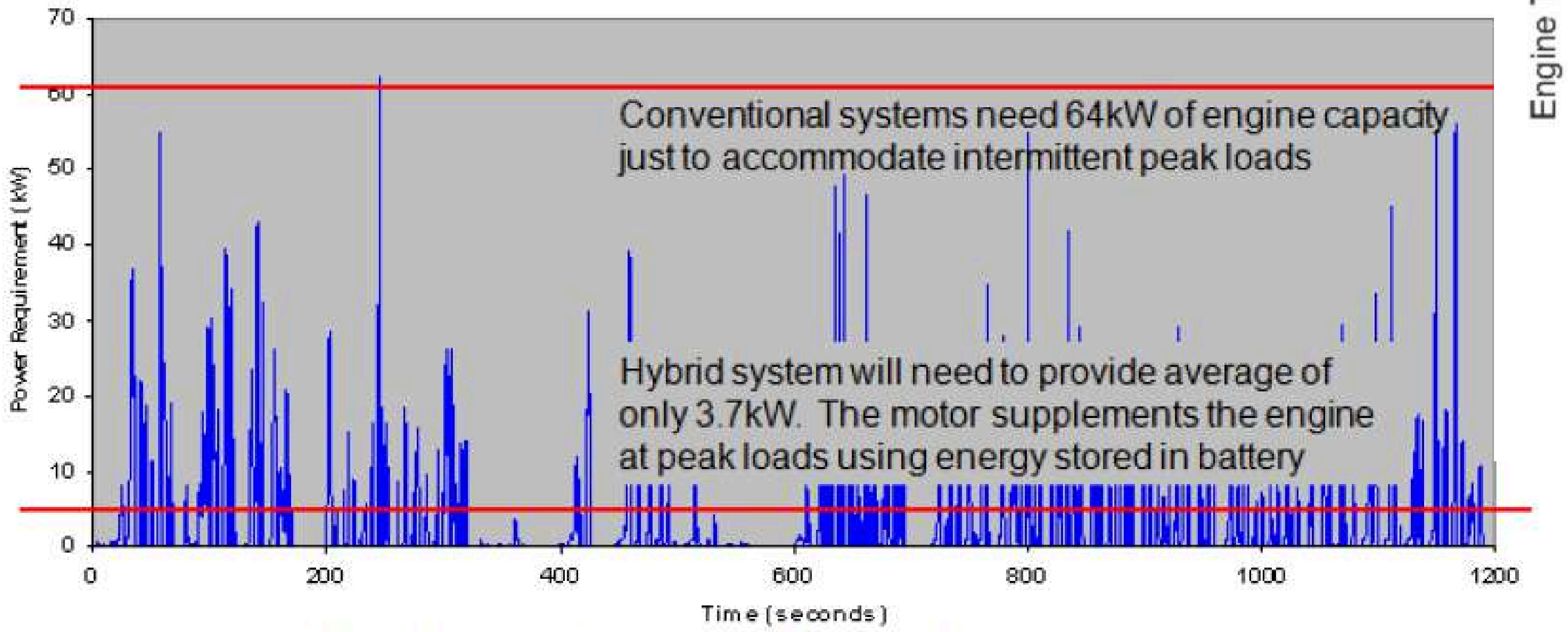


Figure 2.4. Road Load of UP Campus Jeepney driving cycle