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TRANSMISSION POWER MANAGEMENT IN POWER-SPLIT HYBRID ELECTRIC VEHICLE USING RESPONSE SURFACE METHOD AND DATA DRIVEN DESIGN SYNTHESIS

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ABSTRACT

This article aims to model the transmission architecture of a planetary power split Hybrid Electric Vehicle (HEV) to improve fuel efficiency as well as to reduce emission, conforming sustainable design. The model is developed using model based equations, retrieved from literature and Design of Experiment with response surface solution mode. Development of power management strategy for the above, utilizing associated mathematical modeling of the proposed gearset topology guided transmission architecture is disseminated in this work. Design solution for suitable gearset topology is derived by utilizing response surface method and genetic algorithm. The result shows that connection between planetary gear stages, amongst considered variables, holds highest significance and also helps to infer that most suitable configuration is to couple the engine with the second planet carrier for a two-stage power split device. The modelling-based result depicts successful implementation of two stage planetary gear train as power split device with fossil fuel consumption reduction of 49.16%, maximizing electric power utilization for greener transportation.

Keywords: Hybrid Electric Vehicles, Model Based Equations, Mathematical Modelling and Estimation.

NOMENCLATURE

PSHEV	Power Split Hybrid Electric Vehicle
RSM	Response Surface Method
PMS	Power Management Strategy
PSD	Power Split Device
a	Ring to Sun ratio of first Stage PG
b	Ring to Sun ratio of second Stage PG
PG	Planetary Gearsets
p	Connecting link in-between two PGs
m	Overall Vehicle Mass
ICE	Internal Combustion Engine
EM	Electric Motor
E	Engine link to gearset
GA	Genetic Algorithm
CC	Connection in-between Carrier of PG1 and Carrier of PG2
CS	Connection in-between Carrier of PG1 to Sun gear of PG2
SC	Connection in-between Sun gear of PG1 to carrier of PG2
MP	Output Motor Power
EP	Output Engine Power
SS	Sun gear of PG1 link to Sun gear link of PG2
C1	Carrier of PG1
C2	Carrier of PG1
So	Source
S	Sum of Squares
M	Mean sum of squares
F	F-value
P_v	P-value
D_f	Degrees of freedom
P_o	Total power output

1. INTRODUCTION

Greenhouse gas emissions from vehicles propelled by fossil fuels is drawing attention of scientists worldwide. Although a vehicle can be propelled by several alternatives, today only one is readily available: electricity [1 and 2]. Energy efficiency is crucial for such technologies that power these vehicles and thus, power management schemes is necessary to maximize energy conversion efficiency for increased mileage with reduced carbon emissions. The present solution is an electrical propulsion technology that incorporates a completely new architectural drivetrain into the vehicle [3]. PSHEV is a great short term solution that combines electrical and fossil fuel based propulsion to minimize fuel consumption and achieve desired power demand [4]. The new architectural system, however, needs to be optimized to maximize system efficiency to achieve maximum driving distance with low fuel consumption, satisfying the requisite power demand In terms of hybrid propulsion, the weight, size and cost of an HEV is directly related to the efficiency of its electronic power conversion system and fuel conversion system. This paper aims to utilize the fundamental concepts of model based equation of physical components in a PSHEV, to assess power utilization through topology analysis of PSD. Model based Equations of powertrain components are an established method for analyzing and modelling powertrain for HEVs [5, 6 and 7], that facilitates performance tuning and/or design new vehicle systems. There is no literature, however, that elaborates the emphasis on the design and modeling of transmission system for a PSHEV that influences energy utilization. Matlab Based Simulink model is used to evaluate the selected control parameters and obtain best system configuration to represent power flow mathematically.

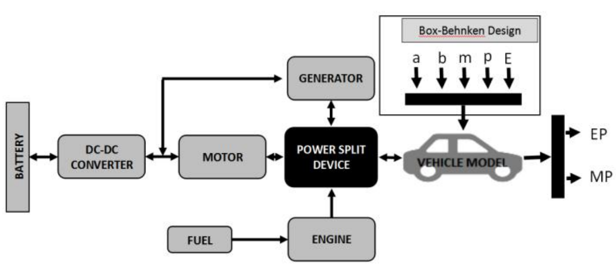

Fig 1: Matlab Model of PSHEV as in Simscape Driveline [12]

Using RSM-based strategic experimentation, analysis of control parameter with response data is carried out for deducing best results and analyzing strategies to satisfy power demand. The resulting mathematical equation is targeted for power management and control through transmission based design synthesis.

2. METHODOLOGY

Simscape Driveline in Simulink is used for experimentation of multiple variations of control parameter [8]. The mathematical modelling is carried out using RSM considering a, b, m, p, E as control parameters. The response variable considered are: *Battery Power*: Denotes output power from EM, *Engine Power*: Denotes output power from ICE. Box-behnken design is used to evaluate distinct variants of control parameters to model relationship between control parameter and response in the form of a mathematical equation to analyze various typologies and deduce power management strategy. A total of 240 types of combination was tested as per Box-Behnken design with aforementioned levels of control parameters (defined by $N = 2k(k - 1) + c$, where k is number of factors and c is the number of central points [9]). Multiple levels of control parameter is utilized for analysis which are as follows:

1. *a*: Minimum value = 2, Maximum value = 5
2. *b*: Minimum value = 2, Maximum value = 5
3. *m*: Minimum value = 1200, Maximum value = 1500
4. *P*: CC, CS, SC and SS
5. *E*: C1, C2, S1 and S2

Parameter 4 and 5 represent discrete data with specified levels. Multiple combination of discrete parameter data fetched unique mathematical relation. For simplification purpose, the electrical power and engine power is combined to arrive at a feasible solution. Genetic Algorithm was further used to find best combination of control parameters for each combination of discrete datasets. The different cases and corresponding regression equation are presented in table 1.

Table 1: RSM Based Regression Equations

P	E	Regression Equation
CC	C1	$P_o = 173 + 68.2\,a + 33.8\,b - 0.506m - 2.28\,a^2 - 2.08\,b^2 + 0.000227\,m^2 - 5.01\,a*b - 0.0197a*m - 0.0013\,b*m$
CS	C1	$P_o = 262 + 61.9\,a + 33.0\,b - 0.517\,m - 2.28\,a^2 - 2.08\,b^2 + 0.000227\,m^2 - 5.01\,a*b - 0.0197\,a*m - 0.0013\,b*m$
SC	C1	$P_o = 188 + 61.2\,a + 31.4\,b - 0.474\,m - 2.28\,a^2 - 2.08b^2 + 0.000227\,m^2 - 5.01\,a*b - 0.0197\,a*m - 0.0013\,b*m$
SS	C1	$P_o = 274 + 69.6\,a + 34.3\,b - 0.548\,m - 2.28\,a^2 - 2.08\,b^2 + 0.000227\,m^2 - 5.01\,a*b - 0.0197\,a*m - 0.0013\,b*m$

CC	C2	$P_o = 183 + 61.3\ a + 39.1\ b - 0.490\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
CS	C2	$P_o = 253 + 54.9\ a + 38.3\ b - 0.501\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
SC	C2	$P_o = 109 + 54.2\ a + 36.6\ b - 0.458\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
SS	C2	$P_o = 249 + 62.6\ a + 39.5\ b - 0.533\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
CC	S1	$P_o = 357 + 55.9\ a + 22.6\ b - 0.548\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
CS	S1	$P_o = 455 + 49.6\ a + 21.8\ b - 0.559\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
SC	S1	$P_o = 269 + 48.8\ a + 20.2\ b - 0.516\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
SS	S1	$P_o = 324 + 57.2\ a + 23.1\ b - 0.590\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
CC	S2	$P_o = 313 + 50.1\ a + 31.7\ b - 0.527\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
CS	S2	$P_o = 374 + 43.8\ a + 30.8\ b - 0.539\ m - 2.28\ a2 - 2.08\ b2 + 0.000227\ m2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
SC	S2	$P_o = 313 + 43.0\ a + 29.2\ b - 0.496\ m - 2.28\ a2 - 2.08\ b2 + 0.000227\ m2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$
SS	S2	$P_o = 280 + 51.4\ a + 32.1\ b - 0.570\ m - 2.28\ a^2 - 2.08\ b^2 + 0.000227\ m^2 - 5.01\ a*b - 0.0197\ a*m - 0.0013\ b*m$

3. RESULTS AND DISCUSSION

Analysis of regression equation through GA [10] as in table 1 reveal multiple regression equation (for each cases) from which best solution was chosen based on the maximum value of vehicle mass (depicting higher passenger/load capacity). Fixing the mass value to 1500Kg the following solution was found suitable, illustrated in table 2. Analyzing the topologies in the table above, MP and EP for different connections were calculated in the Matlab model. It is observed that when PG1 is connected to PG2 via the carrier of the two stages. Maximum power can be drawn from the system as output with minimum utilization of engine (unequal to zero as it will resemble no utilization of engine). Model summary as obtained from minitab statistical software [11] reveal R^2-value of 55.26% with model p-value of 0.0000 and ANOVA result reveal that the highest significance is observed for control parameter P (p-value 0.0000)and interaction of the same with parameter E (p-value 0.0000). Also, interaction in-between parameter a and parameter b fetch high significance value (p-value 0.0420).

Table 2: Results from GA based solution

a	b	m (kg)	p	E	MP* (kW)	EP* (kW)
5	2	1500	CC	C1	81.09	0
4.743	2	1500	SC	C1	14.61	64.67
2	5	1500	CC	C2	49.5	30.36
2	5	1500	SC	C2	0	0
2.022	2.001	1500	SC	S1	0	0

Table 3: ANOVA Table

So	D_f	S	M	F	P_v
Model	42	591305	14078.7	3.77	0.00
Linear	9	152642	16960.2	4.54	0.00
a	1	9248	9247.6	2.47	0.12
b	1	7524	7524.1	2.01	0.16
m	1	0	0.2	0	0.99
p	3	104643	34881.1	9.33	0.00
E	3	31227	10409	2.78	0.04
Square	3	3894	1297.8	0.35	0.79
a*a	1	3	2.7	0.00	0.98
b*b	1	2985	2985.3	0.80	0.37
m*m	1	656	656	0.18	0.68
Interaction (2-way)	30	434769	14492.3	3.88	0.00
a*b	1	6601	6601	1.77	0.19
a*m	1	1899	1899.5	0.51	0.48
a*P	3	21066	7022.1	1.88	0.14
a*E	3	40111	13370.4	3.58	0.02
b*m	1	225	224.7	0.06	0.81
b*P	3	7554	2518	0.67	0.57
b*E	3	26953	8984.3	2.40	0.07
m*P	3	1468	489.2	0.13	0.94
m*E	3	1001	333.5	0.09	0.97
p*E	9	327892	36432.4	9.74	0.00
Error	197	736633	3739.3		
Lack-of-fit	165	619430	3754.1	1.02	0.489
Pure Error	32	117203	3662.6		
Total	239	1327938			

Comparing with the initial single PG model, an increase of 56.47% in electrical power, a reduction of 52.37% in engine power and 49.16% reduction in fossil fuel consumption is observed . Thus, through this design modification the electric power consumption has been maximized and fossil fuel consumption is minimized. From figure 2, it is seen that the RSM based mathematical model (as in minitab software) aids to predict the power distribution for multiple coupling combination (connection in-between first stage PG and second stage PG). There are four possible ways inbetween PG1 and PG2 considering ring 1 and ring 2 is connected as ring to ring connection produces efficient design and also a dominant design.

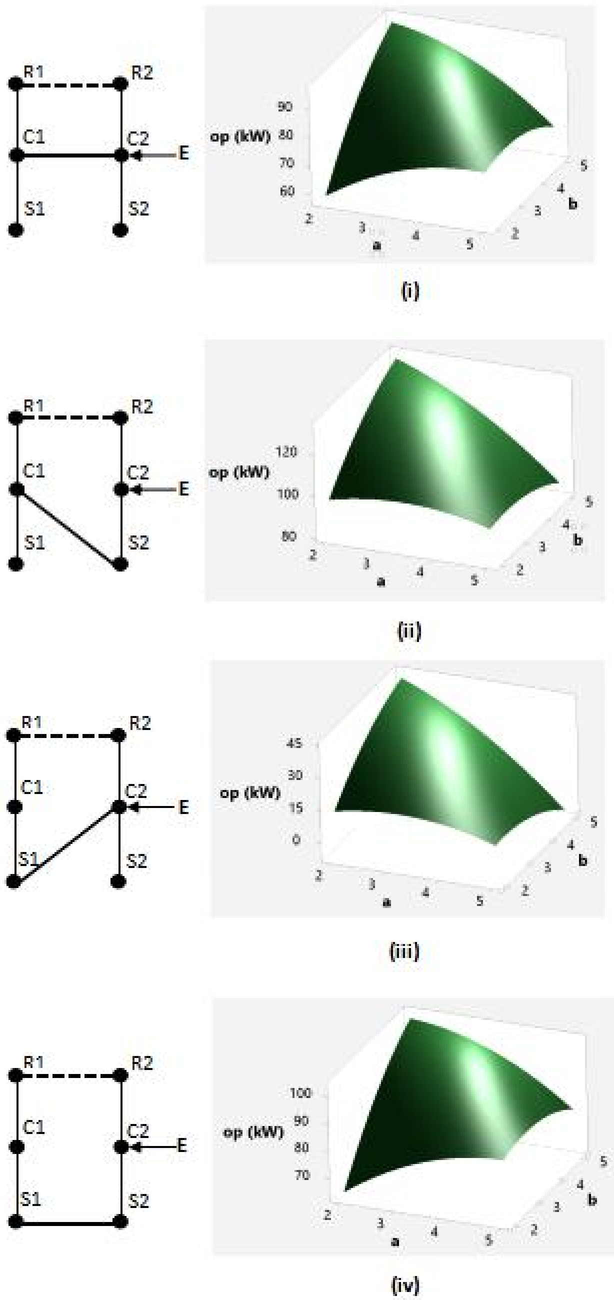

Fig 2: 3D Surface Plot at multiple PG topology

Higher P_o with higher gear ratio is desirable from the point of view of size and weight determining system architecture. This design information is critical in determining the design specification and topology of transmission system. By analyzing the diagrams in (i) and (iv) in Fig 2 it is incumbent to determine the feasibility of the alternatives. Fig 2(i) provides the most realistic P_o values as (ii) and (iv) have P_o more than maximum power of propulsion sources combined (Appendix 2) and (iii) provide low P_o indicating high transmission losses.

4. ASSUMPTIONS AND CONSIDERATIONS

1. Only the relation of select control parameters is tested in this paper with two PGs having same ring gear and generator connected to the sun gear of PG1
2. All vehicle parameters (except the selected control parameters) are left unmodified for all test condition.
3. Internal transmission losses and meshing losses in the PSD is considered as zero.

5. CONCLUSION

The mathematical models developed from the MATLAB/Simulink PSHEV model provided valuable insight for formulating suitable power management strategy. Based on goal driven approach a new PG transmission architecture is deduced which provides better utilization of power sources for vehicle propulsion. In this case, the utilization of electric power is maximized, fossil fuel consumption is reduced and payload carrying capacity is increased by 300kg.

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APPENDIX 1

The data used for RSM analyses is presented below:

Sl No.	a	b	m (kg)	p	E	MP(kW)	EP (kW)
1	2	3.5	1200	SS	C1	86	0
2	2	5	1350	SS	C2	82	0
3	3.5	3.5	1350	CS	S1	256	10.8
4	3.5	5	1200	SS	S2	0	0
5	3.5	2	1500	CC	S1	54	29.3
6	3.5	2	1500	SS	C1	80	0
7	5	3.5	1200	CC	C1	84	0
8	3.5	5	1500	CC	C2	50	30.4
9	3.5	3.5	1350	SC	C1	13	66.8
10	3.5	3.5	1350	SS	S2	0	0
11	5	2	1350	CS	C1	95	0
12	3.5	3.5	1350	CS	S2	102	0
13	3.5	5	1200	SC	S1	0	0
14	5	3.5	1500	SS	S2	0	0
15	3.5	3.5	1350	CC	C1	0	0
16	2	5	1350	SC	C2	0	0
17	2	2	1350	CC	C2	0	0
18	2	5	1350	CS	S1	218	3.8
19	3.5	2	1200	CS	S2	94	0.06
20	5	3.5	1200	SS	C1	84	0
21	3.5	2	1500	SS	S1	0	0
22	2	3.5	1500	CS	C1	105	0.25
23	3.5	3.5	1350	SS	S2	0	0
24	3.5	2	1200	SS	C2	88	0
25	2	5	1350	CC	S1	82	0
26	5	3.5	1500	CS	S1	-105	128
27	3.5	3.5	1350	SS	C1	247	4.38
28	3.5	5	1500	CC	C1	50	30.4
29	2	3.5	1500	SC	S2	167	1.28
30	5	3.5	1500	SS	S1	0	0
31	2	5	1350	SS	C1	87	0
32	3.5	2	1200	SC	S2	176	2.57
33	3.5	3.5	1350	CS	C2	71	9.23
34	5	3.5	1200	CS	C2	70	9.24
35	2	2	1350	SC	C1	31	49.1
36	3.5	2	1200	SC	S1	0	0
37	3.5	3.5	1350	SC	C2	0	0
38	5	3.5	1500	CC	C1	81	0
39	5	2	1350	CC	C2	83	0
40	3.5	2	1200	CC	C2	84	0
41	3.5	5	1500	SS	C2	81	0
42	3.5	3.5	1350	CC	C1	0	0
43	2	3.5	1200	SC	S1	0	0
44	3.5	2	1500	SC	S2	180	1.71
45	5	3.5	1200	SS	S2	0	0
46	5	3.5	1200	SS	S1	0	0
47	2	5	1350	CS	C2	-142	204
48	2	5	1350	SS	S2	0	0
49	3.5	3.5	1350	SS	S1	0	0
50	2	2	1350	SS	C1	83	0
51	2	3.5	1500	SS	C1	83	0
52	3.5	5	1200	SS	C2	84	0
53	5	2	1350	CS	C2	-139	225
54	3.5	3.5	1350	CC	C2	0	0
55	2	5	1350	SS	S1	0	0
56	3.5	2	1200	CS	S1	164	1.69
57	3.5	3.5	1350	CS	S1	256	10.8
58	2	3.5	1200	SS	S2	0	0
59	2	3.5	1200	SC	S2	165	1.87
60	2	3.5	1500	CS	S2	105	0.25
61	3.5	5	1200	SS	S1	0	0
62	3.5	3.5	1350	CS	C1	102	0.19
63	3.5	2	1500	CS	S1	166	1.19
64	3.5	3.5	1350	SS	S2	0	0
65	5	3.5	1500	CS	C1	105	0.15
66	5	2	1350	CC	S2	47	38.6
67	3.5	5	1500	SS	S2	0	0
68	5	3.5	1200	CS	C1	102	0.19
69	5	5	1350	SS	C2	83	0
70	2	3.5	1500	CS	C2	-106	183
71	2	3.5	1500	SC	S1	0	0
72	3.5	3.5	1350	CC	S1	83	0
73	2	5	1350	SC	S1	0	0
74	3.5	3.5	1350	CC	S1	83	0
75	2	5	1350	SC	S2	216	4.14
76	2	5	1350	SC	C1	15	65
77	3.5	3.5	1350	SS	S1	0	0
78	3.5	2	1200	CC	S1	85	0
79	3.5	3.5	1350	SC	S2	-108	135
80	3.5	3.5	1350	CS	C1	102	0.19
81	5	2	1350	SC	S1	0	0
82	5	2	1350	CC	S1	85	0
83	3.5	3.5	1350	CC	S2	64	20.1
84	5	2	1350	SC	C1	15	65.1
85	5	5	1350	CC	C1	0	0
86	2	2	1350	SS	C2	83	0
87	3.5	3.5	1350	CC	S1	83	0
88	5	3.5	1500	SS	C1	81	0
89	5	3.5	1500	CC	S2	57	26.4
90	5	2	1350	SS	C2	91	0
91	2	3.5	1200	CC	S1	84	0
92	2	3.5	1200	CC	C1	83	0
93	3.5	3.5	1350	SS	C2	83	0
94	5	3.5	1500	CS	C2	91	0
95	2	3.5	1500	CC	C2	216	4.14
96	5	3.5	1200	CS	S2	102	0
97	3.5	2	1500	CC	C1	81	0
98	2	2	1350	SC	C2	0	0
99	5	3.5	1200	SC	C1	9.4	70.1
100	3.5	2	1200	CS	C2	-106	192
101	3.5	3.5	1350	SC	C2	0	0
102	3.5	5	1200	CS	S1	-106	123
103	3.5	5	1500	SC	S1	0	0
104	2	3.5	1200	CS	C2	-105	183
105	2	5	1350	CS	C1	118	0
106	3.5	2	1500	CS	S2	115	0

107	5	3.5	1500	SC	C1	8.3	71.1
108	5	5	1350	SS	C1	83	0
109	5	2	1350	SS	S1	0	0
110	3.5	3.5	1350	SS	S1	0	0
111	3.5	3.5	1350	CS	C2	-151	233
112	5	5	1350	CS	C1	116	0.32
113	3.5	5	1200	CC	S2	70	15.4
114	2	3.5	1500	CS	S1	169	1.27
115	2	3.5	1500	SS	C2	81	0
116	2	5	1350	CC	C2	49	32.8
117	3.5	2	1500	SC	C2	0	0
118	3.5	2	1500	CS	C1	93	0.05
119	3.5	2	1200	SS	C1	83	0
120	3.5	3.5	1350	CS	S2	102	0.19
121	5	3.5	1200	SC	S1	-1	79.3
122	5	3.5	1500	SC	C2	-3.3	82.3
123	2	2	1350	CS	C1	-1.5	80.5
124	3.5	3.5	1350	SC	C1	13	66.8
125	3.5	3.5	1350	SC	S2	-108	135
126	5	2	1350	CC	C1	83	0
127	5	3.5	1200	SC	C2	0	0
128	3.5	5	1500	CS	C2	151	105
129	3.5	5	1200	CS	S2	112	0.39
130	3.5	5	1500	SC	C1	8.3	71.1
131	2	3.5	1200	CS	S1	167	1.81
132	3.5	5	1500	CC	S1	78	0
133	5	5	1350	CC	C2	0	0
134	3.5	2	1200	CS	C1	94	0.06
135	2	3.5	1500	CC	C1	0	0
136	5	3.5	1500	CC	S1	81	0
137	3.5	3.5	1350	SS	C1	82	0
138	5	5	1350	SC	C2	0	0
139	3.5	3.5	1350	SS	C1	82	0
140	3.5	2	1500	CC	S2	54	29.3
141	3.5	2	1200	CC	C1	84	0
142	5	3.5	1500	SC	S1	0	0
143	3.5	2	1200	SC	C2	0	0
144	5	2	1350	CS	S1	213	3.4
145	3.5	5	1500	CS	S1	-110	137
146	2	2	1350	CS	C2	-57	141
147	2	3.5	1200	CC	S2	71	13.7
148	3.5	5	1500	SC	S2	-93	118
149	2	3.5	1500	SS	S1	0	0
150	3.5	2	1200	SS	S2	0	0
151	3.5	3.5	1350	CC	C2	0	0
152	3.5	3.5	1350	SC	S1	0	0
153	3.5	5	1500	CC	S2	67	15.4
154	2	3.5	1200	CS	S2	105	0.32
155	2	3.5	1500	SS	S2	0	0
156	5	5	1350	SC	C1	6.8	72.9
157	2	3.5	1200	CC	C2	83	0.01
158	3.5	5	1500	SS	S1	0	0
159	5	3.5	1200	SC	S2	-95	113
160	2	2	1350	SC	S2	134	0.87
161	3.5	3.5	1350	SC	C1	13	66.8
162	3.5	5	1500	CS	C1	-3.3	82.3
163	5	3.5	1200	CC	S2	59	26.4
164	3.5	5	1200	SC	S2	-100	123
165	3.5	3.5	1350	SC	S1	0	0
166	5	3.5	1500	CS	S2	105	0.15
167	5	5	1350	SS	S1	0	0
168	3.5	5	1500	CS	S2	115	0.31
169	3.5	3.5	1350	CS	C2	-151	233
170	3.5	5	1200	CS	C2	153	105
171	2	3.5	1500	SC	C1	20	59.7
172	2	3.5	1200	SS	S1	0	0
173	5	3.5	1200	SS	C2	85	0
174	2	2	1350	CS	S1	128	0.68
175	5	5	1350	CS	C2	0	0
176	5	2	1350	SC	C2	0	0
177	2	3.5	1200	CS	C1	105	0.32
178	5	5	1350	SC	S2	-81	91.4
179	2	3.5	1200	SC	C2	0	0
180	3.5	3.5	1350	CC	S2	64	20.1
181	2	5	1350	CC	S2	73	10.5
182	3.5	5	1200	CC	C1	71	13.7
183	3.5	2	1500	SS	S2	0	0
184	5	3.5	1500	SS	C2	83	0
185	5	5	1350	CS	S1	-93	103
186	3.5	3.5	1350	CS	S1	256	10.8
187	5	5	1350	CC	S2	64	20.2
188	3.5	5	1200	CS	C1	-1.6	0.42
189	5	5	1350	CC	S1	83	0
190	3.5	5	1200	SC	C2	0	0
191	5	5	1350	SC	S1	0	0
192	3.5	2	1200	SC	C1	0	0
193	2	3.5	1200	SS	C2	83	0
194	2	2	1350	SC	S1	0	0
195	2	2	1350	CC	C1	0	0
196	3.5	2	1200	SS	S1	-1	79.3
197	3.5	5	1500	SC	C2	0	0
198	3.5	2	1500	CS	C2	-106	192
199	3.5	2	1500	CC	C2	81	0
200	3.5	3.5	1350	SC	C2	0	0
201	3.5	5	1200	CC	S1	84	0
202	3.5	3.5	1350	CS	C1	102	0.19
203	2	2	1350	CC	S2	64	19.9
204	5	3.5	1500	CC	C2	81	0
205	2	3.5	1500	SC	C2	0	0
206	3.5	3.5	1350	SC	S1	0	0
207	3.5	3.5	1350	CC	S2	64	20.1
208	5	3.5	1200	CC	S1	84	0
209	3.5	3.5	1350	SS	C2	83	0
210	3.5	5	1200	CC	C2	50	30.4
211	3.5	3.5	1350	CS	S2	102	0.19
212	2	5	1350	CS	S2	118	0.52
213	2	3.5	1500	CC	S1	169	1.27
214	3.5	3.5	1350	SS	C2	83	0
215	3.5	2	1500	SS	C2	85	0
216	5	2	1350	CS	S2	95	0.05
217	3.5	2	1500	SC	C1	20	59.7
218	5	2	1350	SC	S2	0	0
219	5	2	1350	SS	S2	0	0
220	3.5	5	1200	SC	C1	9.4	70.1
221	3.5	5	1500	SS	C1	83	0
222	2	2	1350	SS	S1	0	0
223	3.5	3.5	1350	CC	C1	0	0
224	5	5	1350	CS	S2	116	0.32
225	5	5	1350	SS	S2	0	0
226	5	3.5	1200	CC	C2	84	0
227	5	3.5	1500	SC	S2	-94	119
228	2	2	1350	CS	S2	83	0
229	2	2	1350	CC	S1	87	0.03
230	2	3.5	1200	SC	C1	0	0
231	5	3.5	1200	CS	S1	103	0.3
232	3.5	2	1500	SC	S1	81	0
233	3.5	3.5	1350	SC	S2	201	2.72
234	3.5	3.5	1350	CC	C2	65	18.4
235	2	2	1350	SS	S2	0	0
236	3.5	5	1200	SS	C1	88	0
237	2	5	1350	CC	C1	0	0
238	5	2	1350	SS	C1	81	0
239	3.5	2	1200	CC	S2	56	29.3
240	2	3.5	1500	CC	S2	69	13.7

APPENDIX 2

The Matlab simulation parameters as referred from [12] are as follows:

1. *Vehicle Parameters*- Frontal area: $3m^2$, Drag coefficient: 0.4, Air density = 1.18, tire radius: 0.3m.
2. *Engine Parameters*- Maximum Power: 50kW, Speed at Maximum Power: 5500rpm, Max. Speed: 7000rpm, type: SI Engine
3. *Other Parameters*- The winding ratio for DC to DC converter is 2.48, battery nominal voltage is set to 201.6 volts, motor power is 30 kW and generator power is 15 kW