On-road Contactless Power Transfer-Drive Range Extension - A Case Study

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Contents

- Contactless power transfer.
- Model of electric vehicle and battery.
- Simulated EV and assumptions made.
- Case study for various charging scenarios.
- Description of the case studies.
- Observations and conclusions.

- Is contactless charging while driving and at the stoplights feasible

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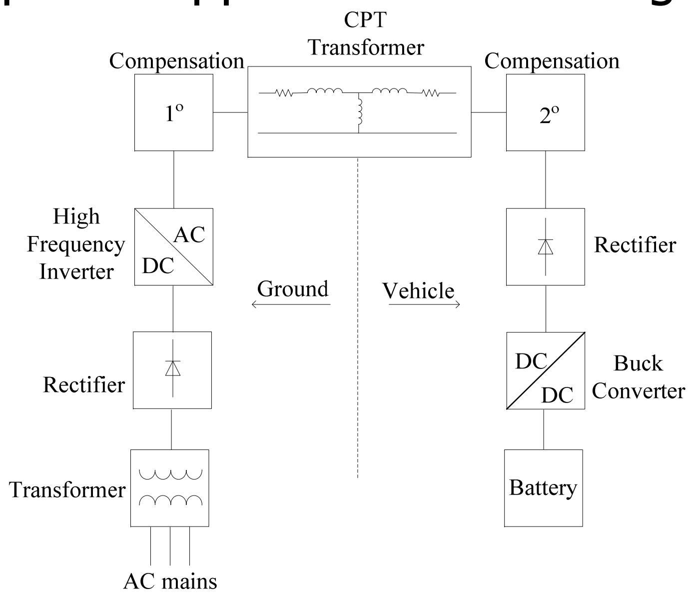
EV have to be charged

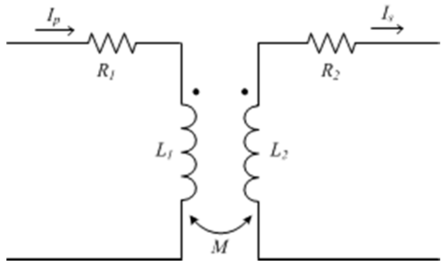
Contactless Power Transfer

- Inductive power transfer employs a resonating air-cored transformer principle.
- Safe, reliable and maintenance free operation.
- Potential high power application : EV charging.



Entire scheme for CPT-EV charging

Concept

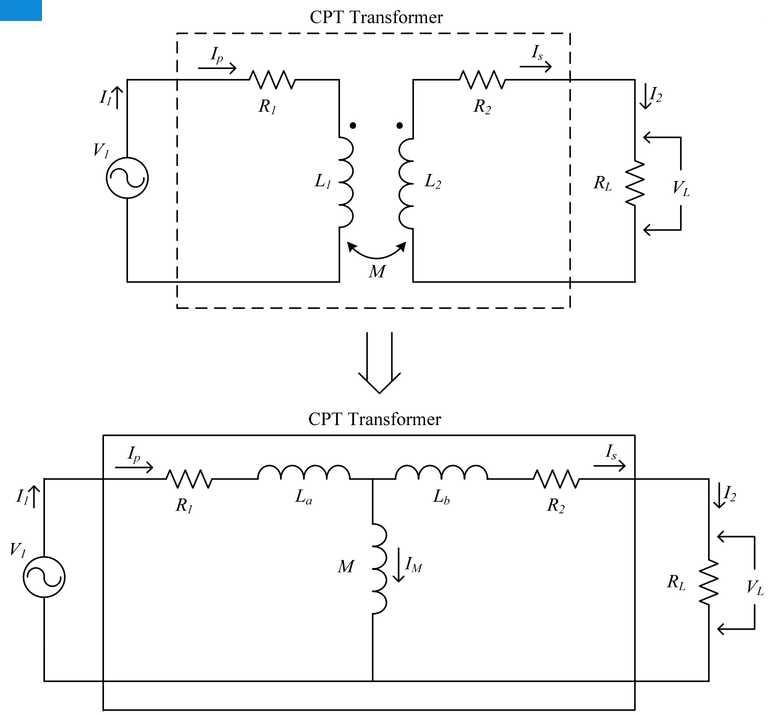


- The physics at work – electric transformer

- Flux linkage between primary and secondary
- Large air gap between primary secondary

- Resonance to increase power transfer capability

Basic CPT transformer analysis



$$\eta = \frac{R_L}{(R_L + R_2)\left(1 + \frac{R1(R_2+R_L)}{\omega^2 M^2}\right) + R1\left(\frac{L_b+M}{M}\right)^2}$$

$$\omega \gg \frac{\sqrt{R_1(R_2 + R_L)}}{M}$$

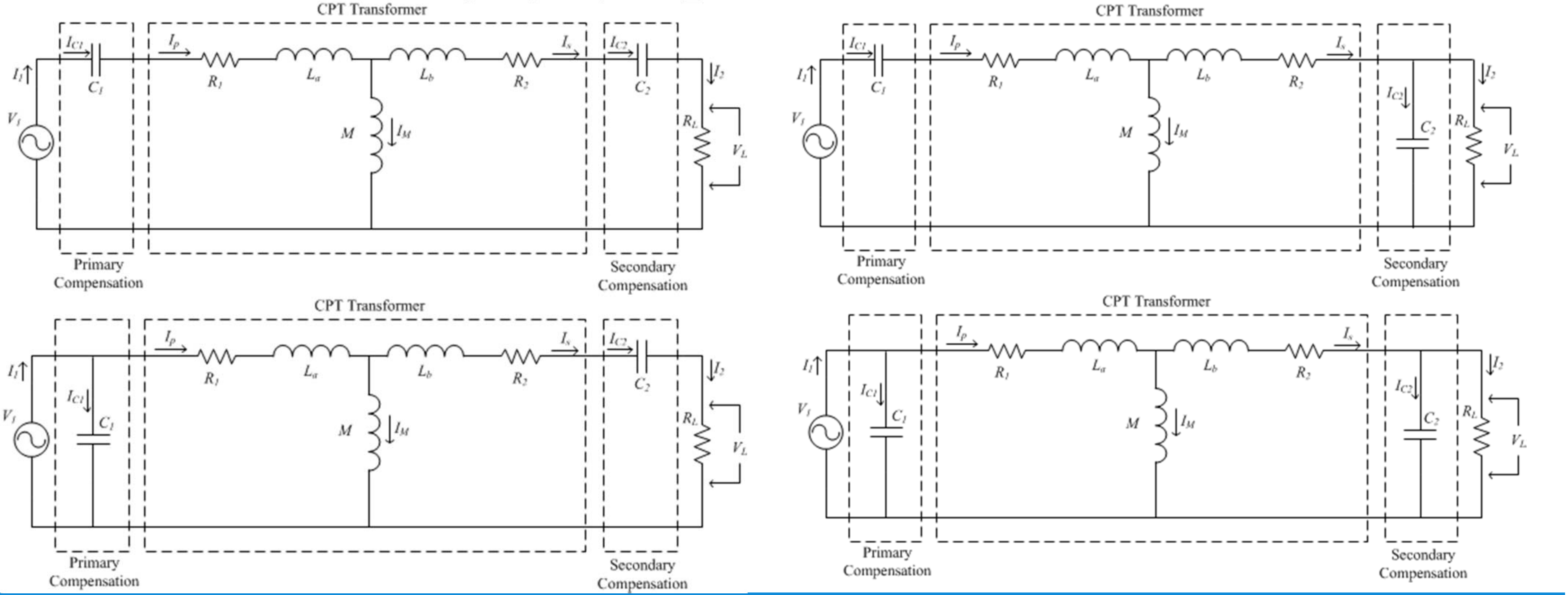
$$\eta_{\max} = \frac{R_L}{R_L + R_2 + \frac{R_1(L_b+M)^2}{M^2}}$$

- Low power transfer capability
- Lower input power factor

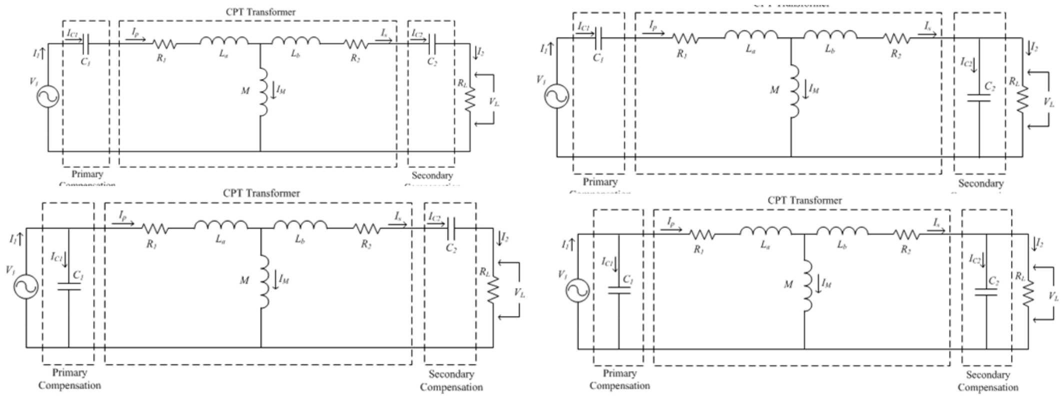
Capacitive compensation

- Secondary – Increase power transfer capability
- Primary – Reduce VA rating of the source

Series-Series (SS), Series-Parallel (SP), Parallel-Series (PS) and Parallel-Parallel (PP) topologies



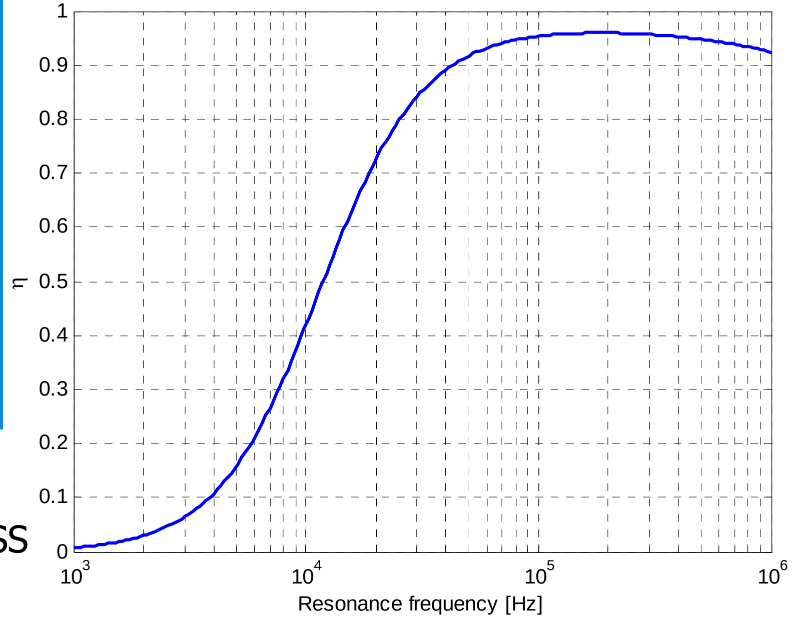
Efficiency



SS and PS topologies	$\eta = \dfrac{R_L}{(R_L + R_2)\left(1 + \frac{R_1(R_2+R_L)}{\omega^2 M^2}\right)}$
SP and PP topologies	$\eta = \dfrac{R_L}{R_L + R_2 + \frac{R_2 R_L^2}{\omega^2 (L_b+M)^2} + \frac{R_1 R_2^2}{\omega^2 M^2} + \frac{R_1\left((L_b+M)\omega^2 + \frac{R_2 R_L}{\omega^2 (L_b+M)}\right)^2}{\omega^2 M^2}}$

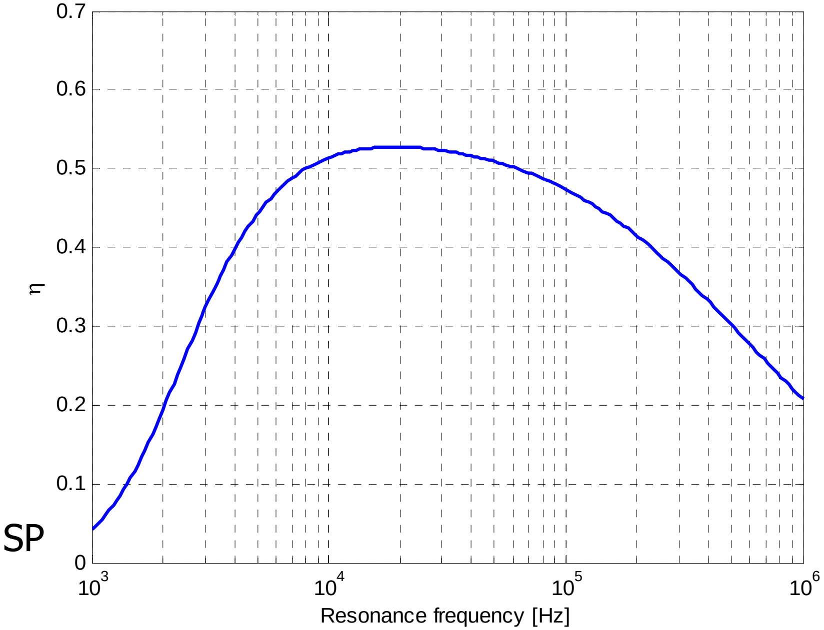
Maximum efficiency and conditions

SS and PS topologies	$\eta_{\max} = \dfrac{R_L}{R_L + R_2}$	$\omega \gg \dfrac{\sqrt{R_1(R_2 + R_L)}}{M}$
SP and PP topologies	$\eta_{\max} = \dfrac{R_L}{R_L + R_2 + \frac{R_1(L_b+M)^2}{M^2}}$	$\omega \gg \dfrac{\sqrt{R_2 R_L^2 M^2 + R_1 R_2^2 (L_b + M)^2}}{(L_b + M)M}$



η
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10^3
10^4
10^5
10^6
Resonance frequency [Hz]

SS



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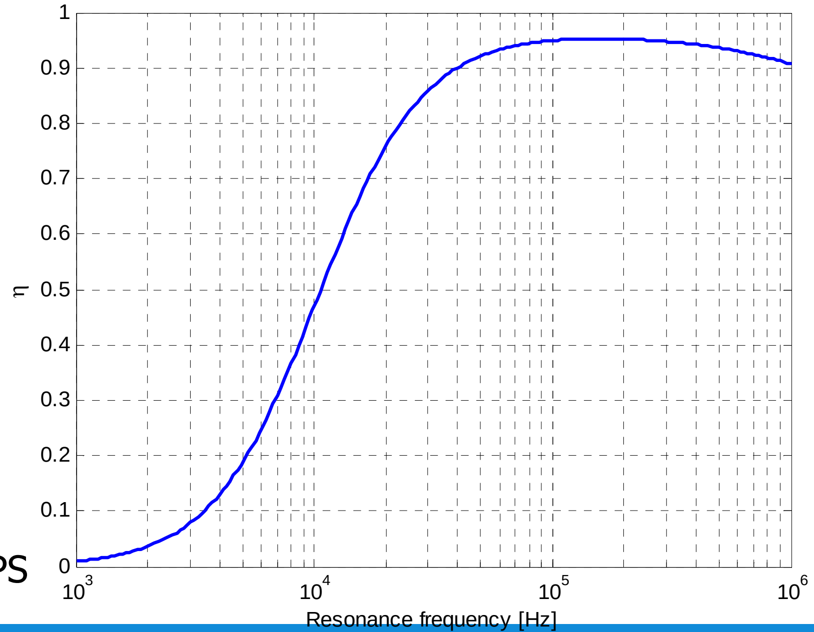
Resonance frequency [Hz]

SP



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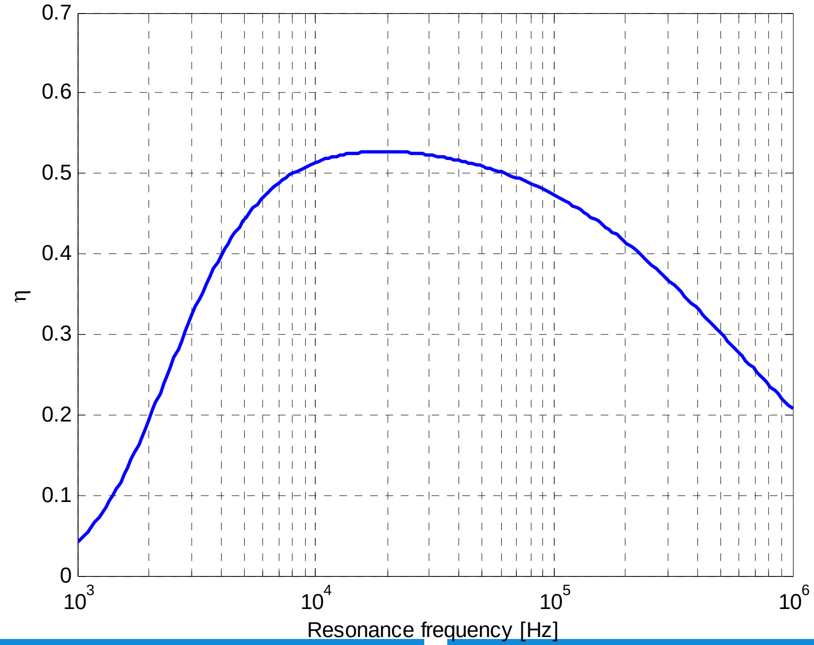

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Resonance frequency [Hz]

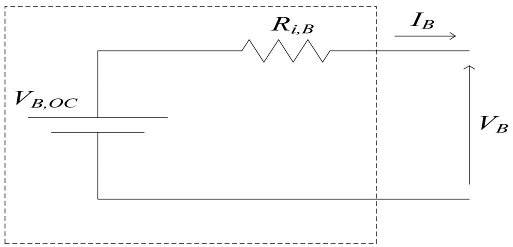
PP

Model of the Electric Vehicle and Battery

- Power requirement of an EV categorized as:
  - Base load - P_{base} ≈800 W.
  - Rolling resistance - $P_{roll} = C_{rr} mg \cos\theta |v|$
  - Aerodynamic drag - $P_{drag} = 1/2 C_d \rho |v|^3 A$
  - Gravitational load - $P_g = mg \sin\theta |v|$
  - Inertial load - $P_{acc} = ma|v|$

$$P_{load} = P_{base} + P_{roll} + P_{drag} + P_g + P_{acc}$$

Battery model used:



List of symbols used:
C_{rr}- Coefficient of rolling resistance
m – Mass of the vehicle
g – Acceleration due to gravity
Θ – Angle of inclination
v – Instantaneous velocity of the vehicle
C_d – Coefficient of drag
ρ – Density of air

Simulated EV and assumptions made

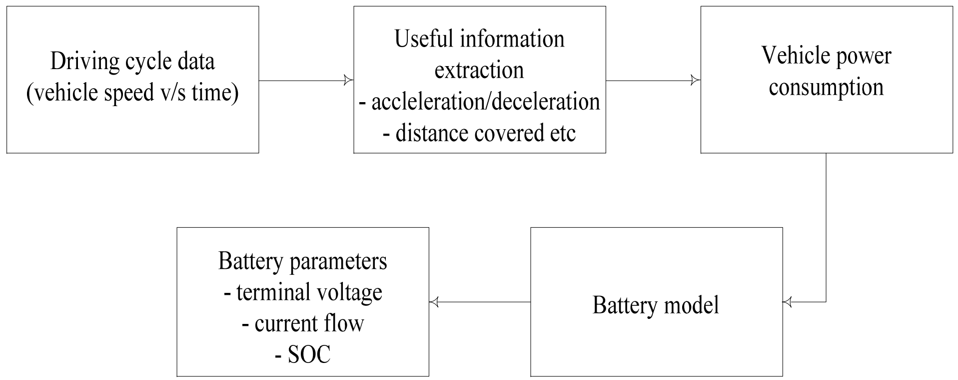
Vehicle	Mass	1600 kg
	Frontal area	2.7 m^2
	Co-efficient of rolling resistance	0.01
	Co-efficient of drag	0.28
Battery	Current capacity	90 Ah
	Energy capacity	24 kWh

Assumptions used:

- Overall efficiency of drive train assumed as 80 %.
- Efficiency of power transfer from wheel to battery assumed as 40 %.
- Initial SOC of battery assumed as 80 %.
- All roads are assumed to be horizontal.
- CPT power transfer efficiency to EV assumed as 80 %.

Case study for various charging scenarios

- Case study A (Charging at the traffic signals)
  - U.S. standard FTP 72 (Federal Test Procedure) cycle also called Urban Dynamometer Driving Schedule (UDDS).
  - European standard ECE-EUDC combined urban test cycle.
  - Japanese standard JC08 urban test cycle.
- Case study B (Charging while driving in highways)
  - HighWay Fuel Economic Test (HWFET) cycle considered back to back
  - Mountien Energy Expensive Driving Cycle (MEEDC)



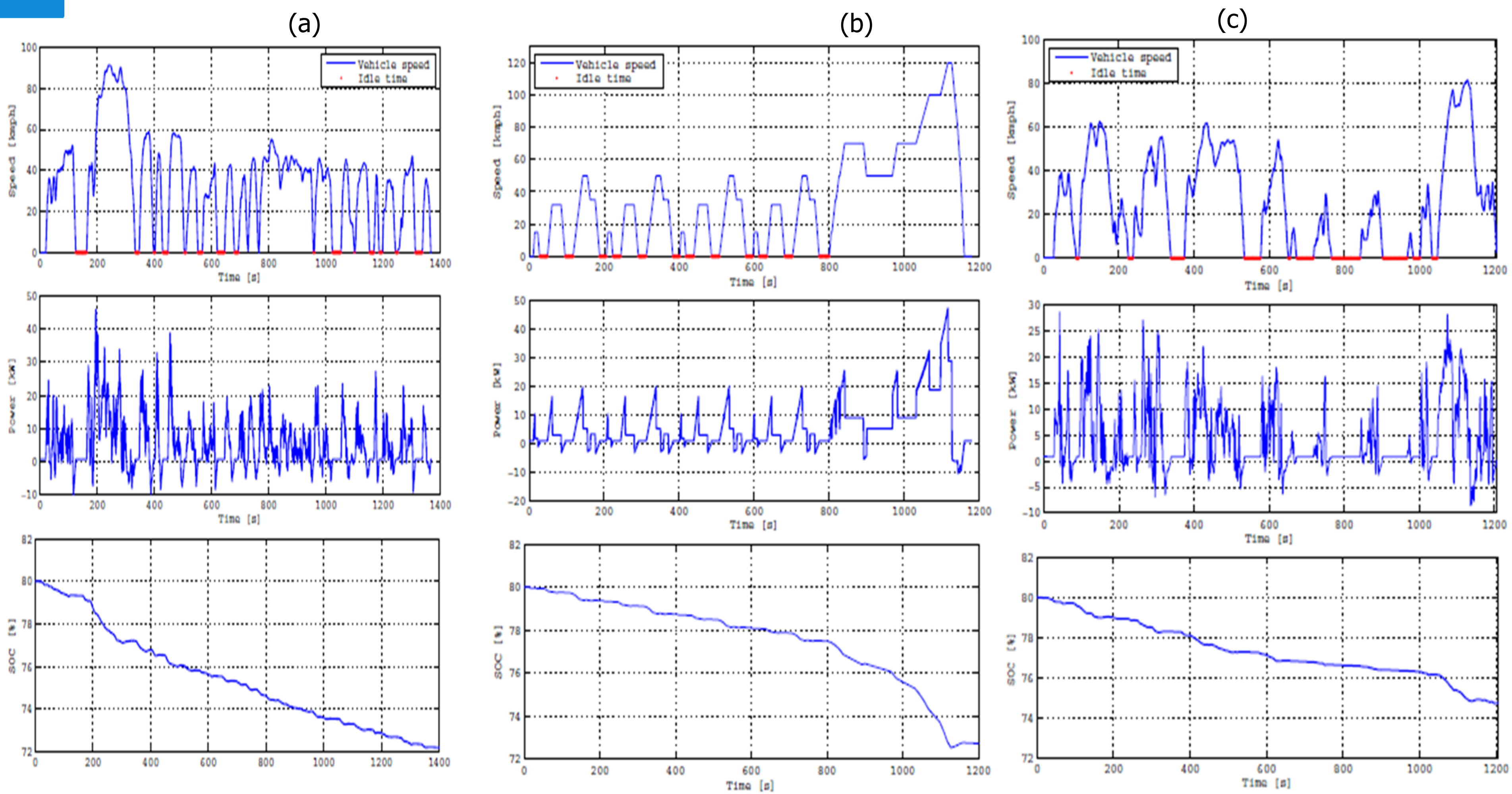
Procedure for battery parameter calculation

Case study A – Charging at traffic signals

	UDDS	ECE-EUDC	JC08
Duration (s)	1369	1180	1204
Distance travelled (km)	12.0	11.0	8.2
Average speed (kmph)	31.5	33.5	24.4
Maximum speed (kmph)	90.9	120	81.6
Total Time spent idling during the journey (s)	234	261	330
% Time spent idling	17.1	22.1	27.4

Comparison of the three driving cycles for the charging at traffic lights scenario

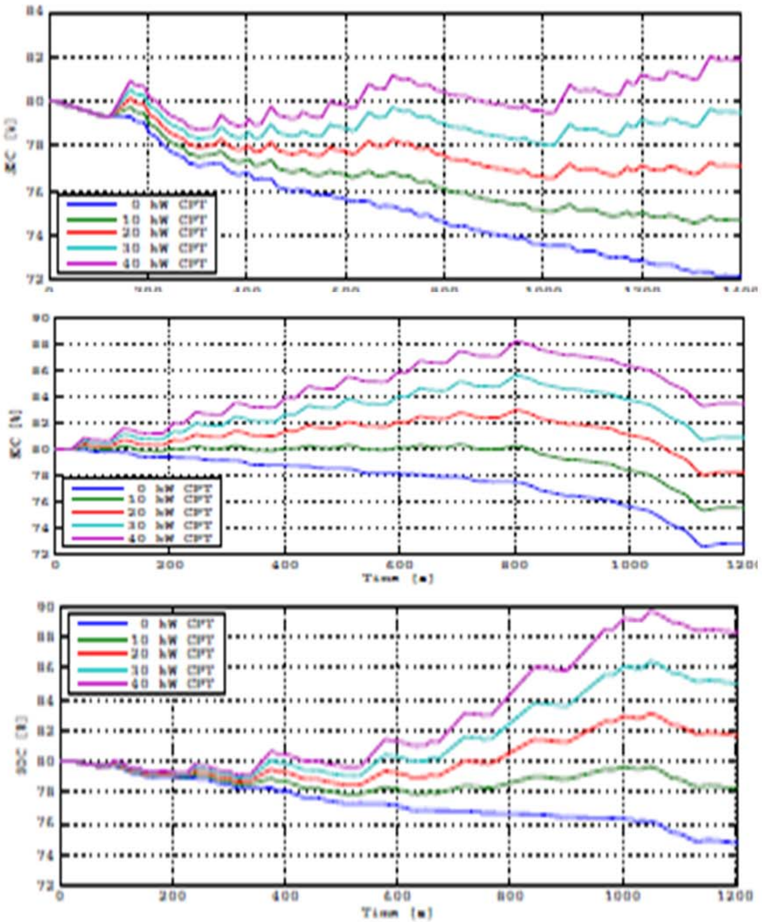
Case study A – Charging at traffic signals



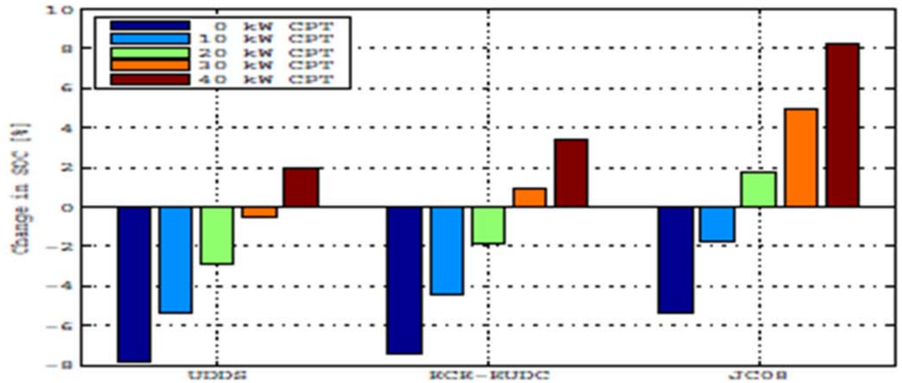
Vehicle speed, battery power flow and SOC of battery for (a) UDDS and (b) ECE-EUDC driving cycles (c)

Case study A – Charging at traffic signals

(a)

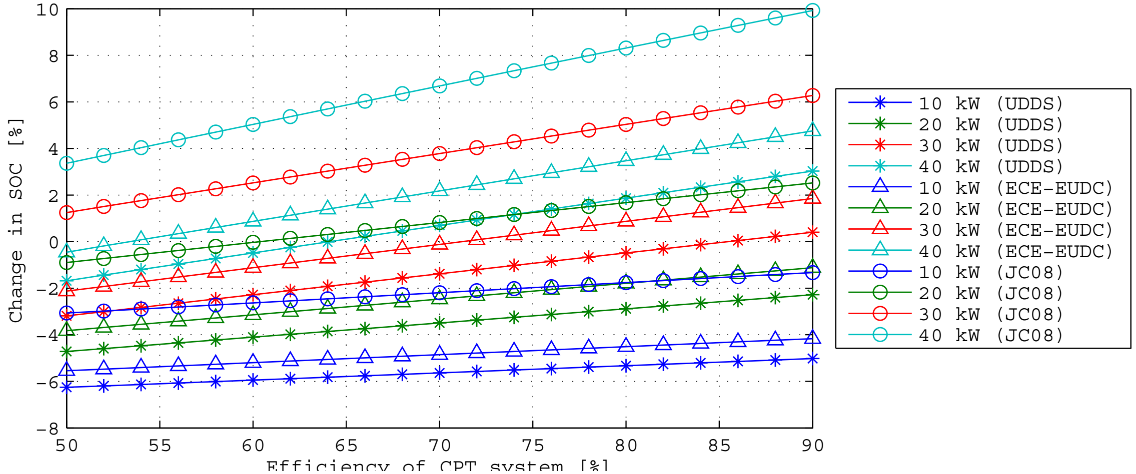


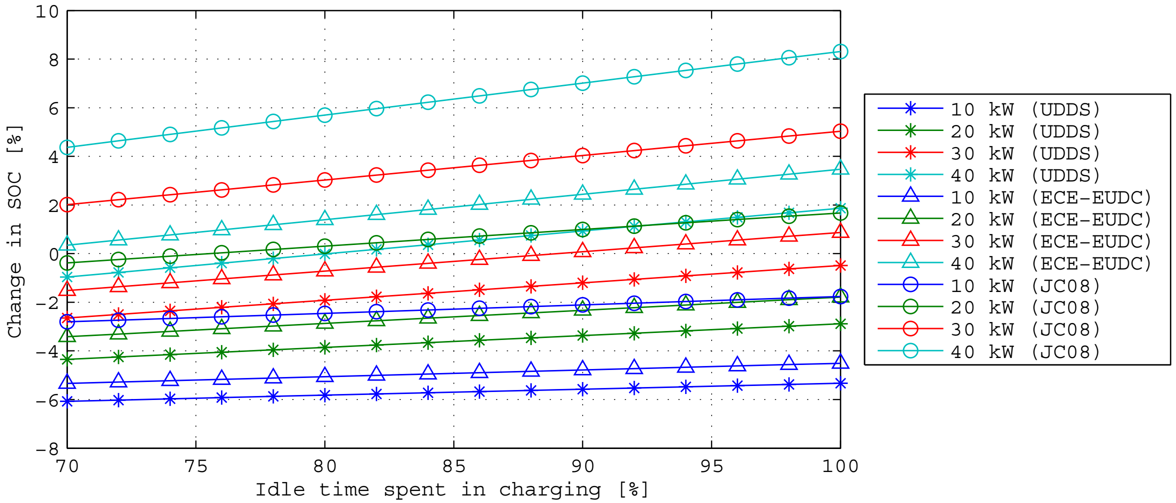
(b)



(a) SOC of battery for different driving cycles (b) change in SOC

Case study A – Charging at traffic signals





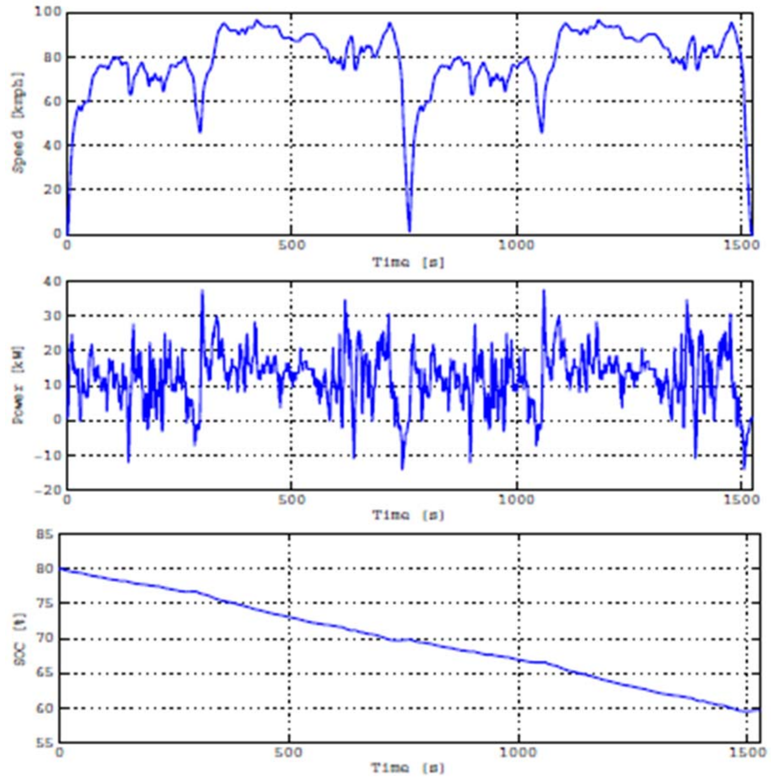
Driving cycles with varying efficiencies CPT system and varying idle time

Case study B – Charging while driving

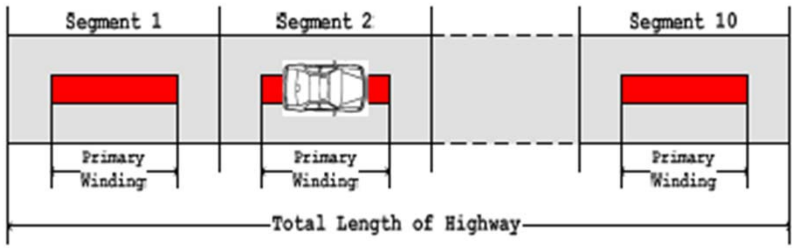
(a)

Duration (s)	Distance travelled (km)	Average speed (kmph)	Maximum speed (kmph)
1526	32.9	77	96.4

(b)`,m

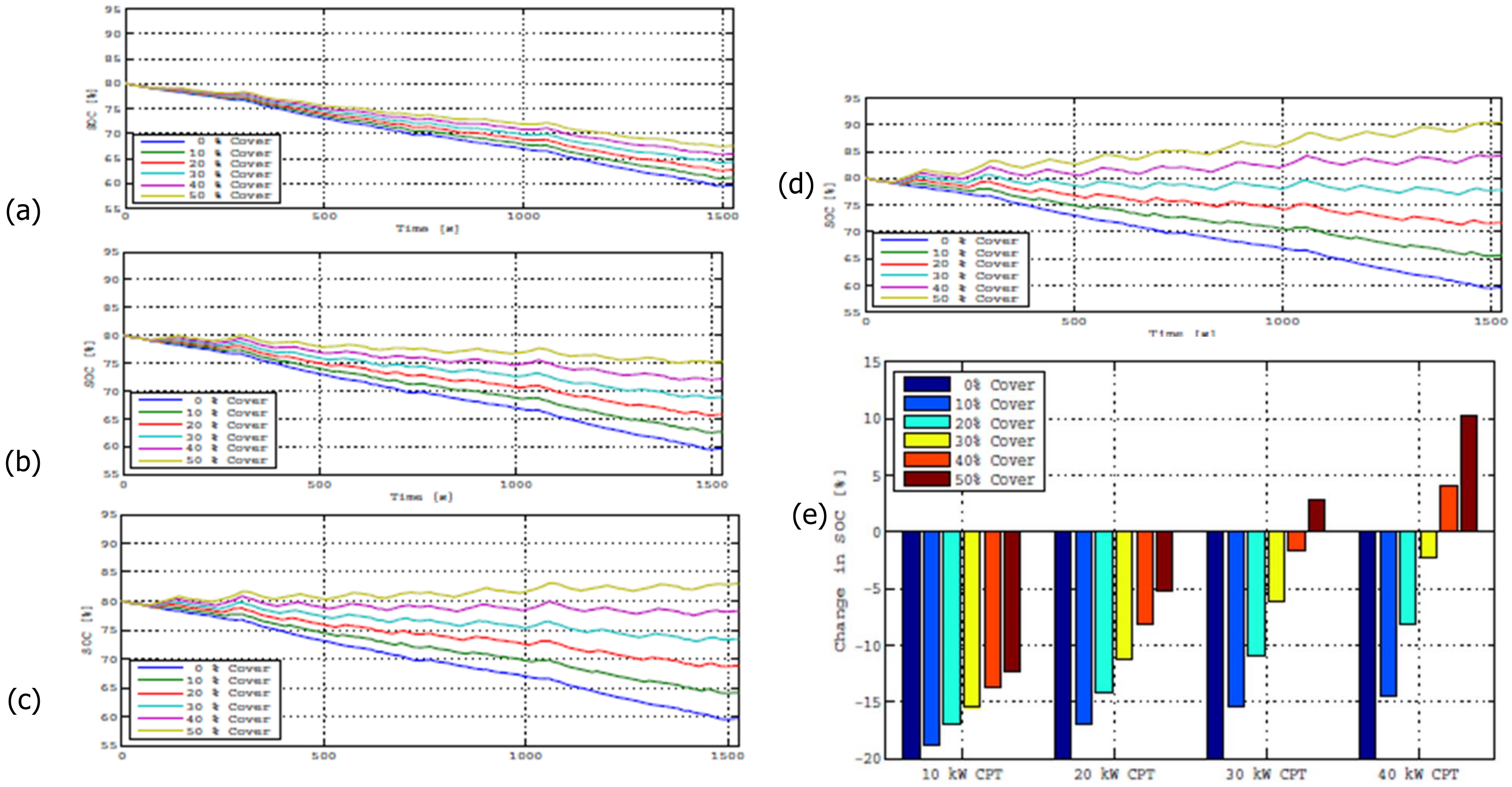


(c)



(a) Characteristics of HWFET 2 (b)Vehicle speed, battery power flow and SOC for HWFET2 (b) Primary winding coverage

Case study B – Charging while driving



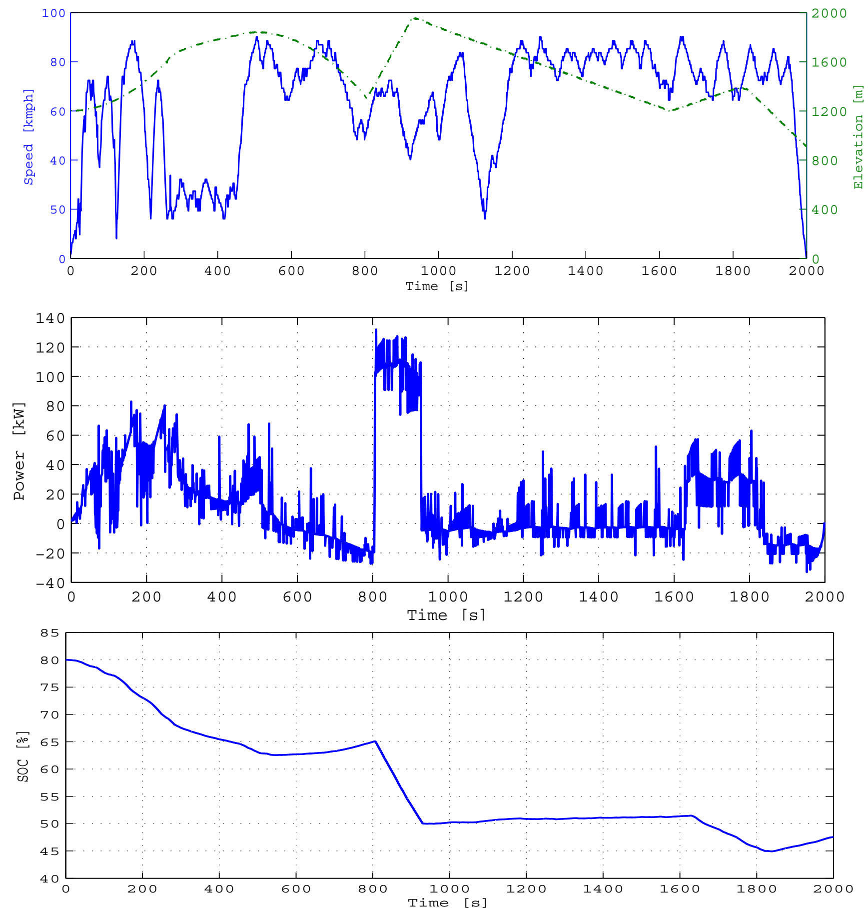
SOC of battery for (a) 10kW, (b) 20kW, (c) 30kW, (d) 40kW CPT and (e) Change in SOC for the entire duration of HWFET2

Case study B – Charging while driving

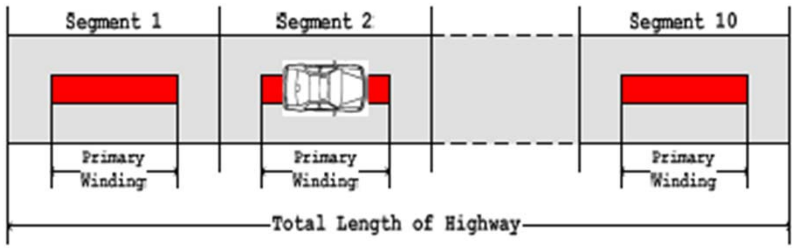
(a)

Duration (s)	Distance travelled (km)	Average speed (kmph)	Maximum speed (kmph)
2000	35.8	65	90.1

(b)`,m

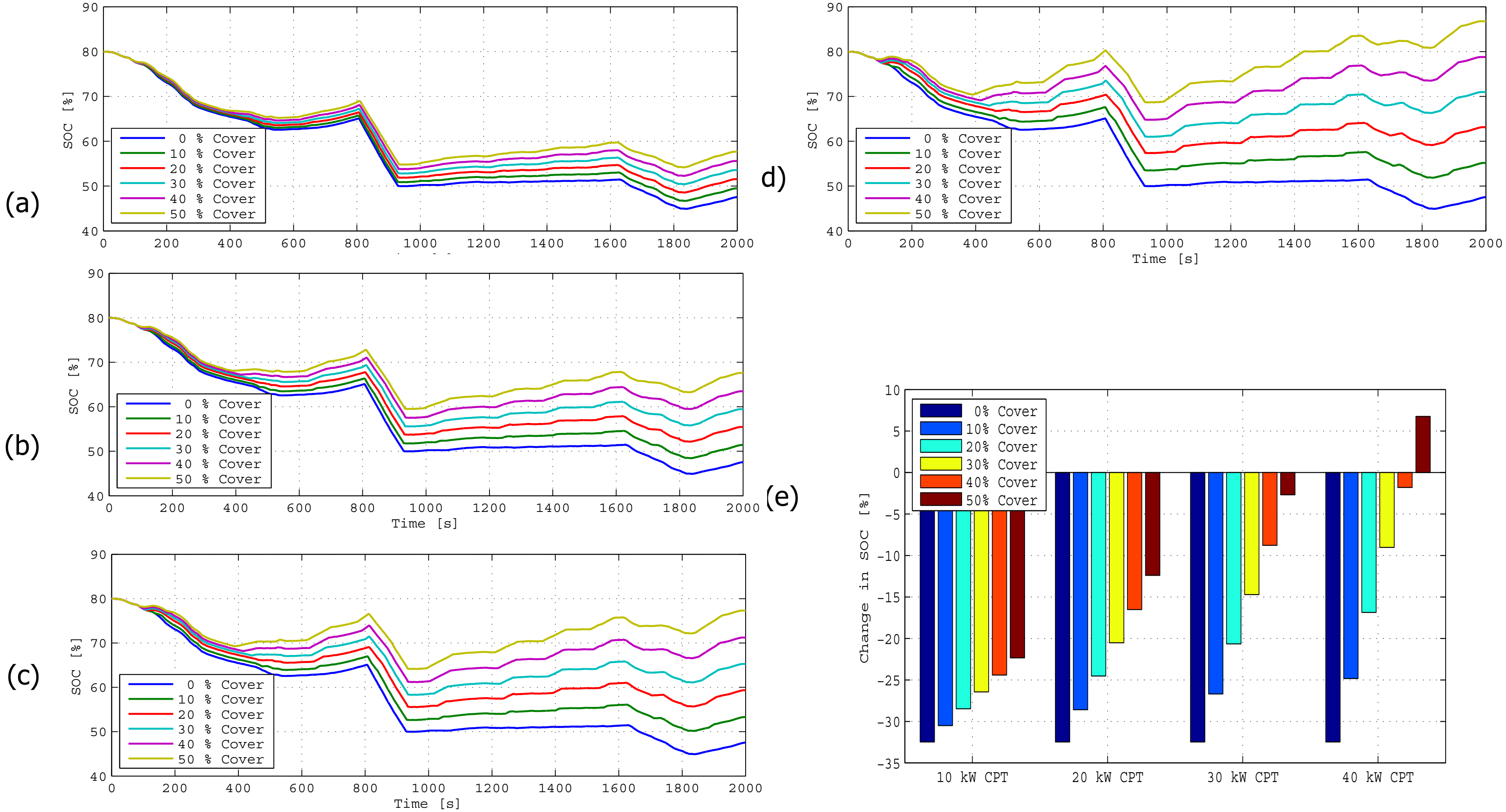


(c)



(a) Characteristics of MEEDC (b)Vehicle speed, battery power flow and SOC for MEEDC(b) Primary winding coverage

Case study B – Charging while driving



SOC of battery for (a) 10kW, (b) 20kW, (c) 30kW, (d) 40kW CPT and (e) Change in SOC for the entire duration of MEEDC

Observations and Conclusions

- Case study A
  - With 20 kW CPT, the range of vehicle has increased to 172% and 311% for UDDS and ECE-EUDC respectively.
  - In case of JC08 driving cycle, range has increased to 194%.
  - With 30 kW CPT, change in SOC for UDDS and ECE-EUDC cycle is almost zero. In case of JC08, it is observed at 20 kW itself.
- Case study B
  - With CPT of 40 kW, 37% increase in range is observed at a highway cover of 10%
  - With 30 kW CPT a highway cover of 40%, the change in SOC of battery during the during the journey is close to 0%,
  - The same observation can be made for MEEDC driving cycle with 30 kW CPT and a highway cover of 50%.