A New Energy Management System of Directly-Driven Electric Vehicle with Electronic Gearshift and Regenerative Braking

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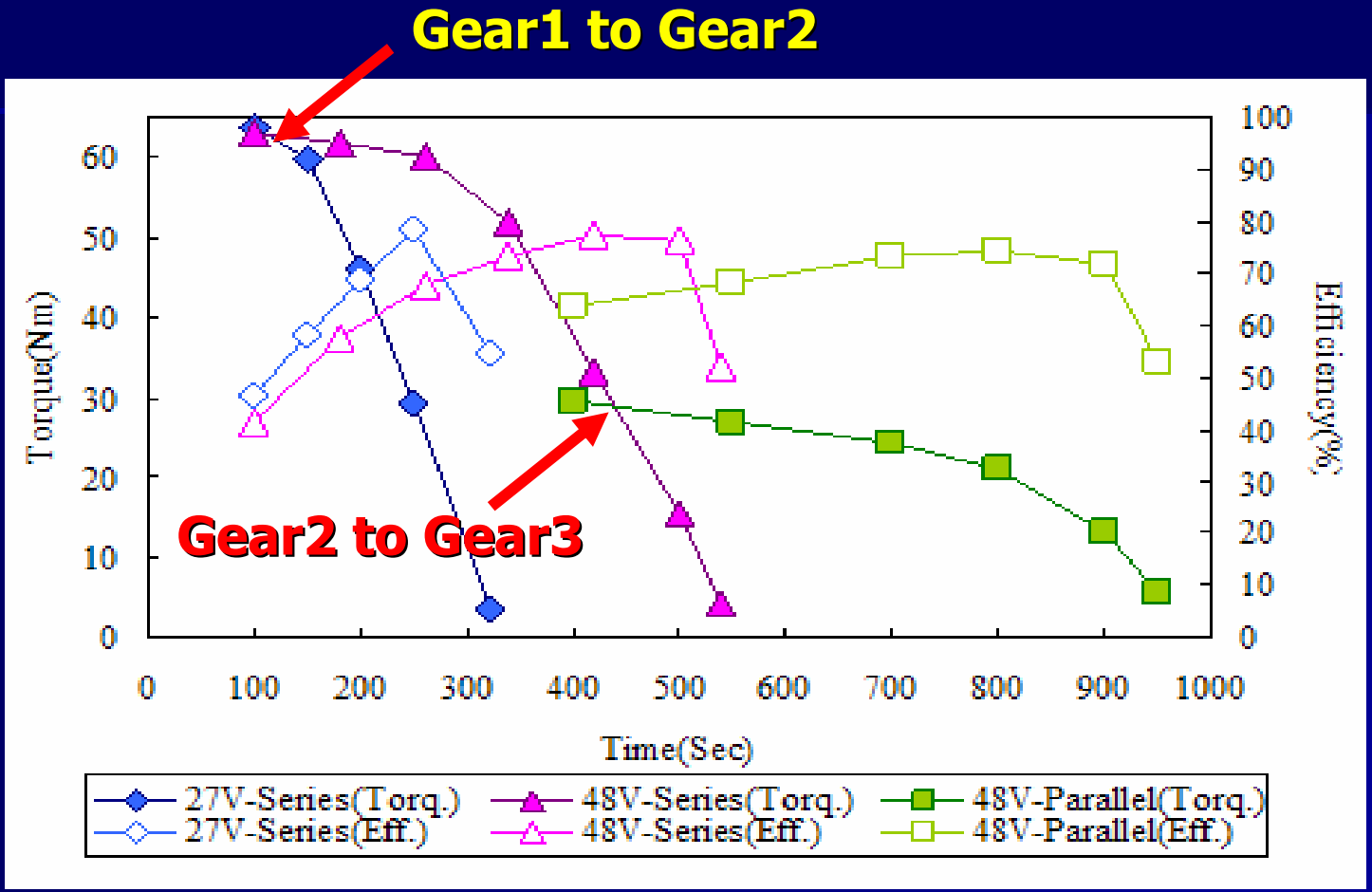
Objective

- A new energy management system with electronic gearshift and regenerative braking
- To improve the efficiency and driving range of electric vehicles.

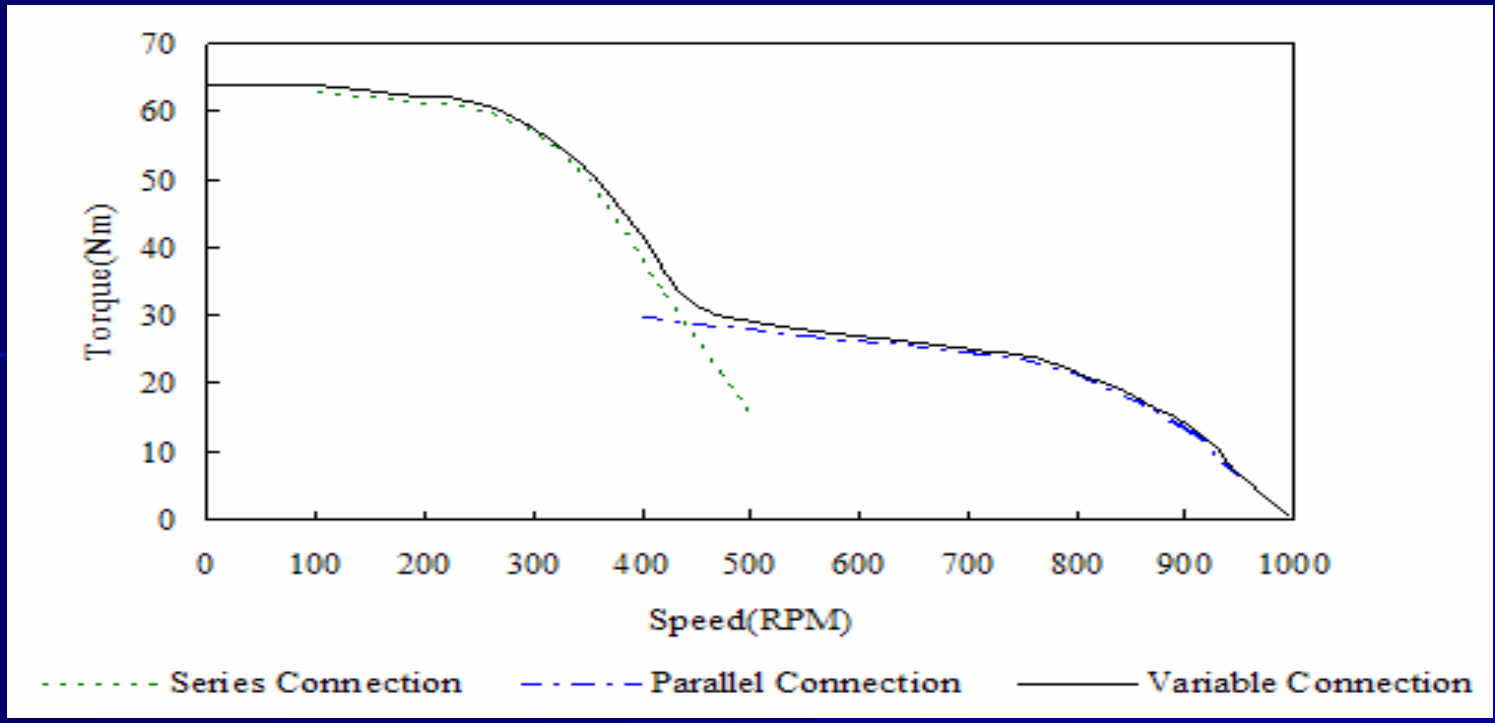
Wheel Motor on Electric Motorcycle

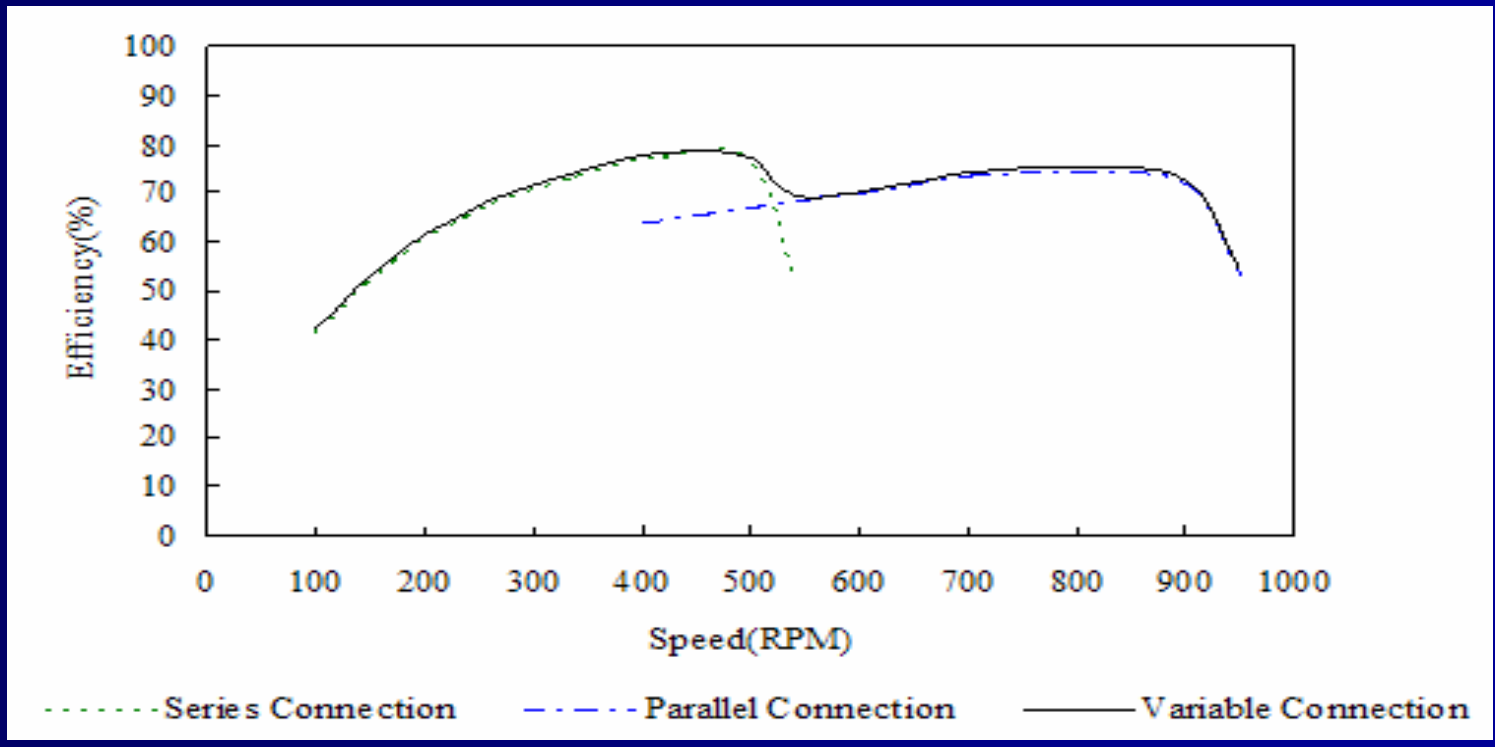
Gearshift points?



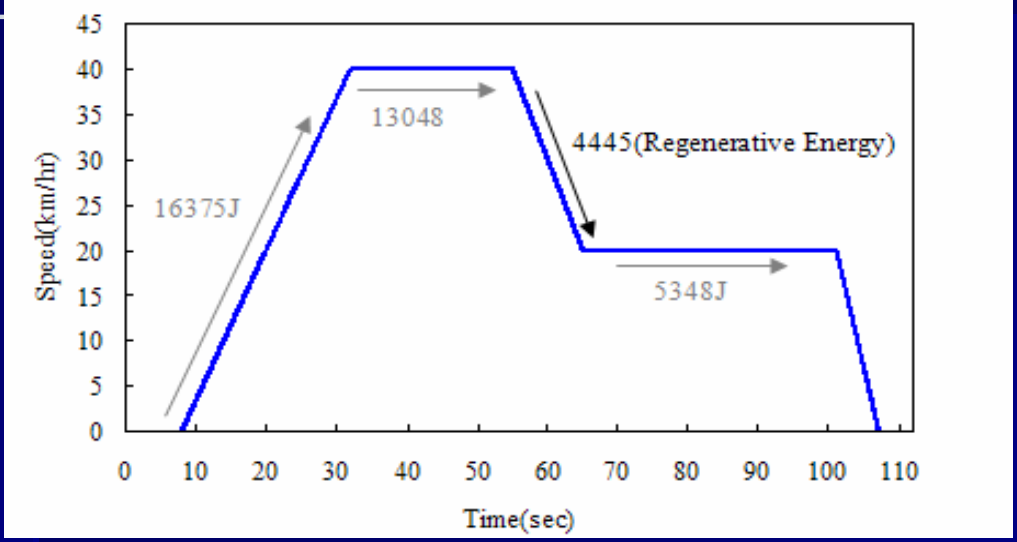
Torque Mode	Shift Point
1st Gear → 2nd Gear	120*RPM*
2nd Gear → 3rd Gear	450*RPM*

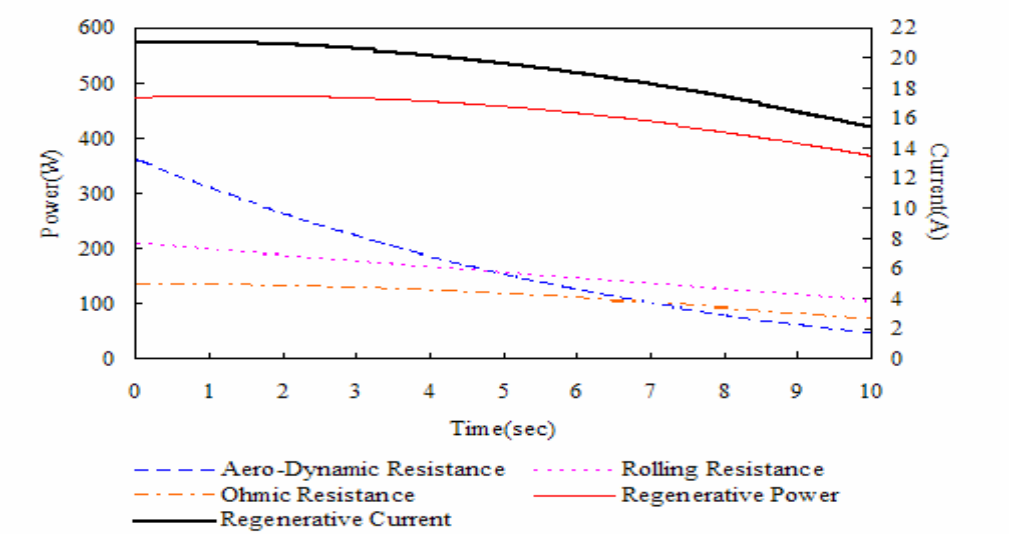
Efficiency Mode	Shift Point
1st Gear → 2nd Gear	280*RPM*
1st Gear → 2nd Gear	510*RPM*


70
60
50
40
30
20
10
0
Torque(Nm)
0
100
200
300
400
500
600
700
800
900
1000
Speed(RPM)
Series Connection
Parallel Connection
Variable Connection


100
90
80
70
60
50
40
30
20
10
0
Efficiency(%)
0
100
200
300
400
500
600
700
800
900
1000
Speed(RPM)
Series Connection
Parallel Connection
Variable Connection

ECE47: restorable energy during regenerative braking (simulation)





Energy used per cycle ：34771J
Restorable energy ：4445J

(12.8%)

Kinetic energy ：8796J

Rolling friction loss : 1552J

Aerodynamic loss : 1686J

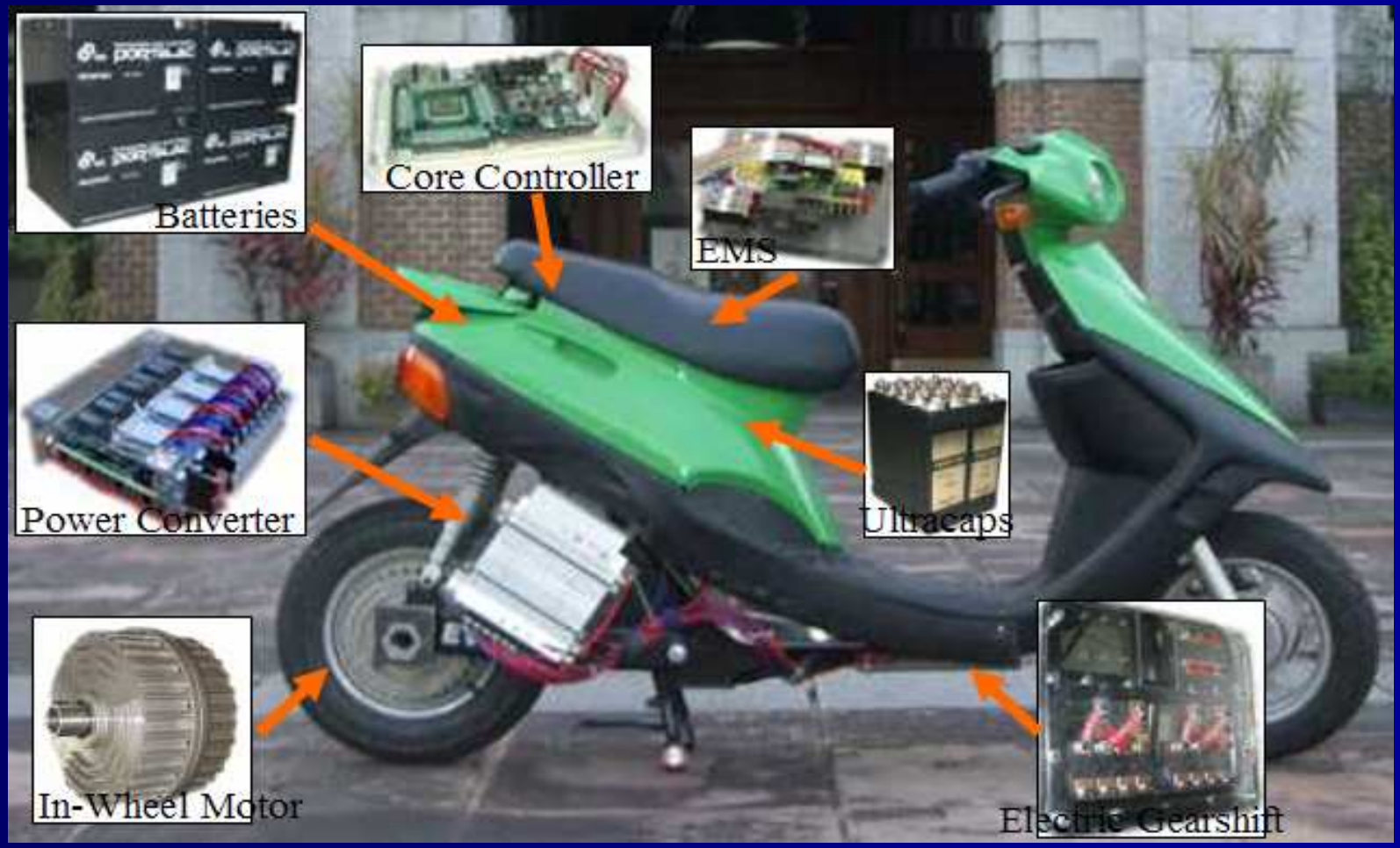
Restorable energy : 4445J

→ **50.53%**

Parameters for performance test

Test standard	ECE47(CNS3105)
Ambient temperature	28.8℃
Relative humidity	79%
Gross weight of vehicle	124*kg*
Weight of driver	66*kg*
Motor type	Directly-driven dc brushless motor
Drive	Independent phase H-bridge
Motor power	1.85*kW@340rpm*
Power source	48*V*26*AH lead acid battery*
	27*V*170*F* ultracapacitor
Gearshift	3 electronic gears for acceleration, 1 for regenerative braking
Brake system	Electronic and mechanical

Propulsion control and energy management system

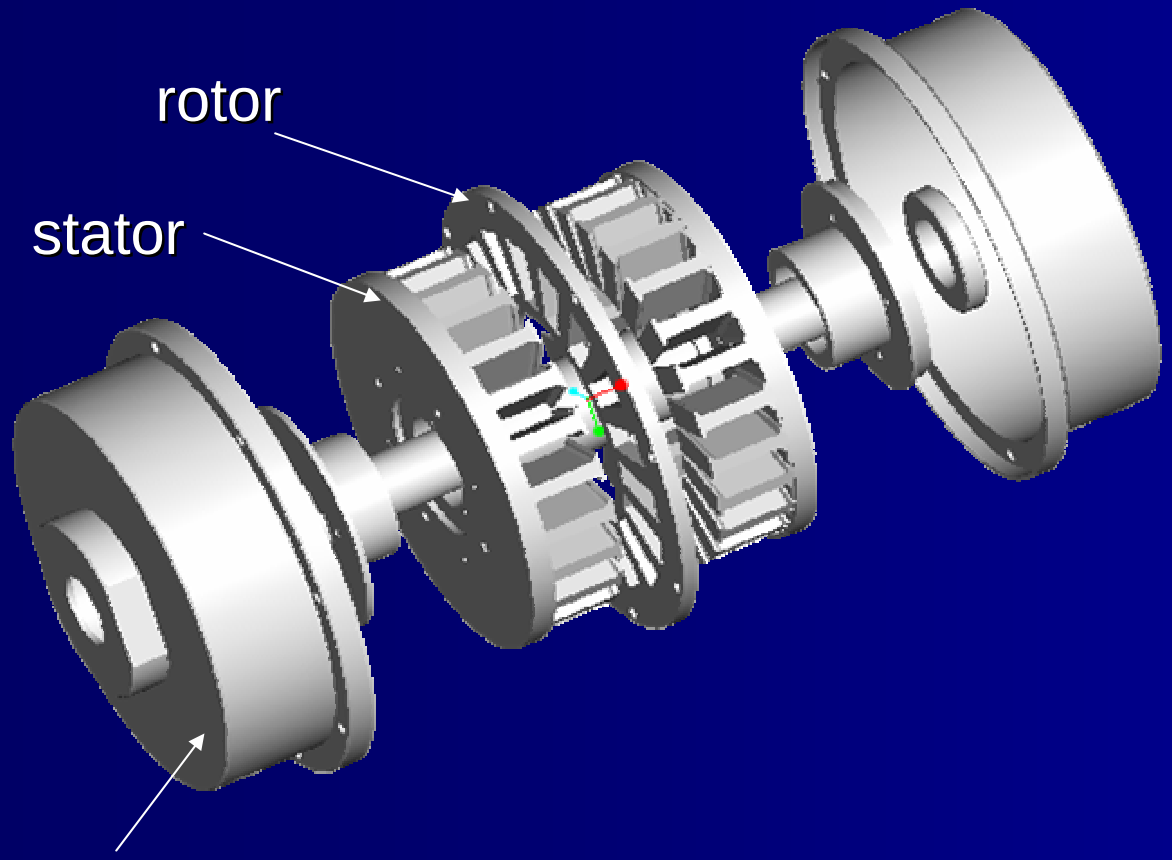


Power source

- Batteries (4x12V, 26*Ah*)
  - High energy density (Wh/kg)
  - Cruising phase

- Ultracapacitors (10x2.7V, 360A)
  - High power density (W/kg)
  - Start, acceleration phase
  - Regenerative braking

Wheel Motor Configuration



Features

4 phases

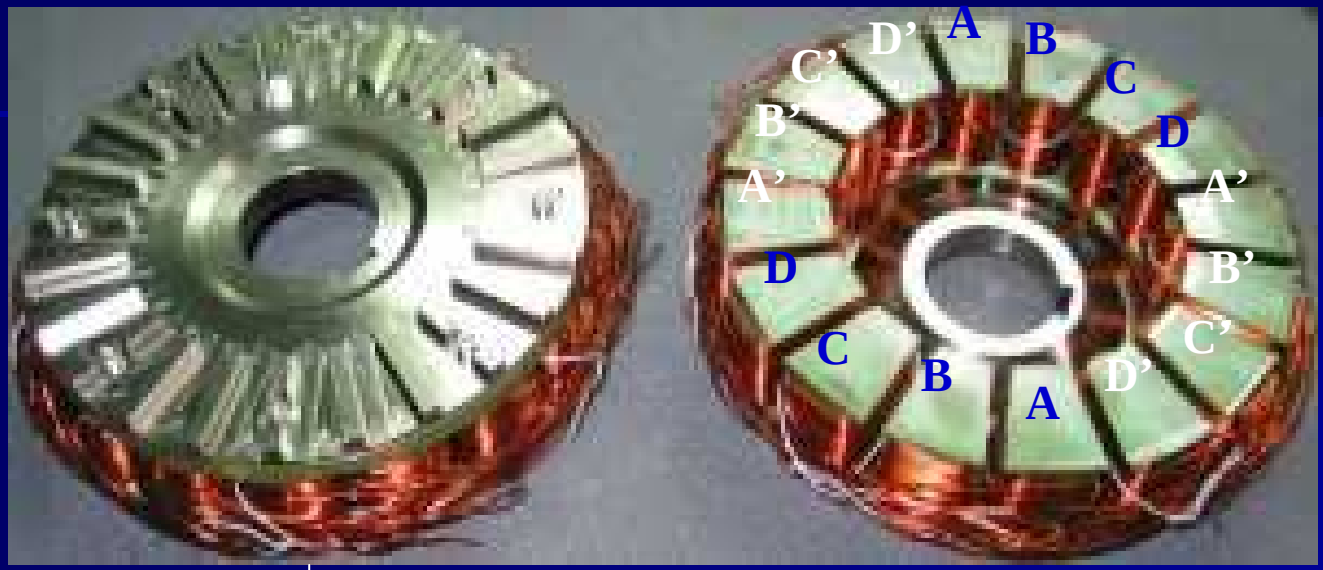
64 Nm (max.)

950 rpm (max.)

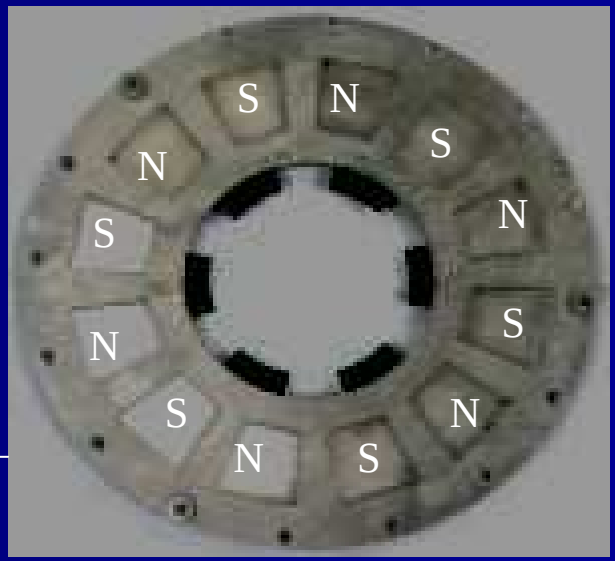
1.85 KW@340rpm

Weight 15kg

Stator and Rotor

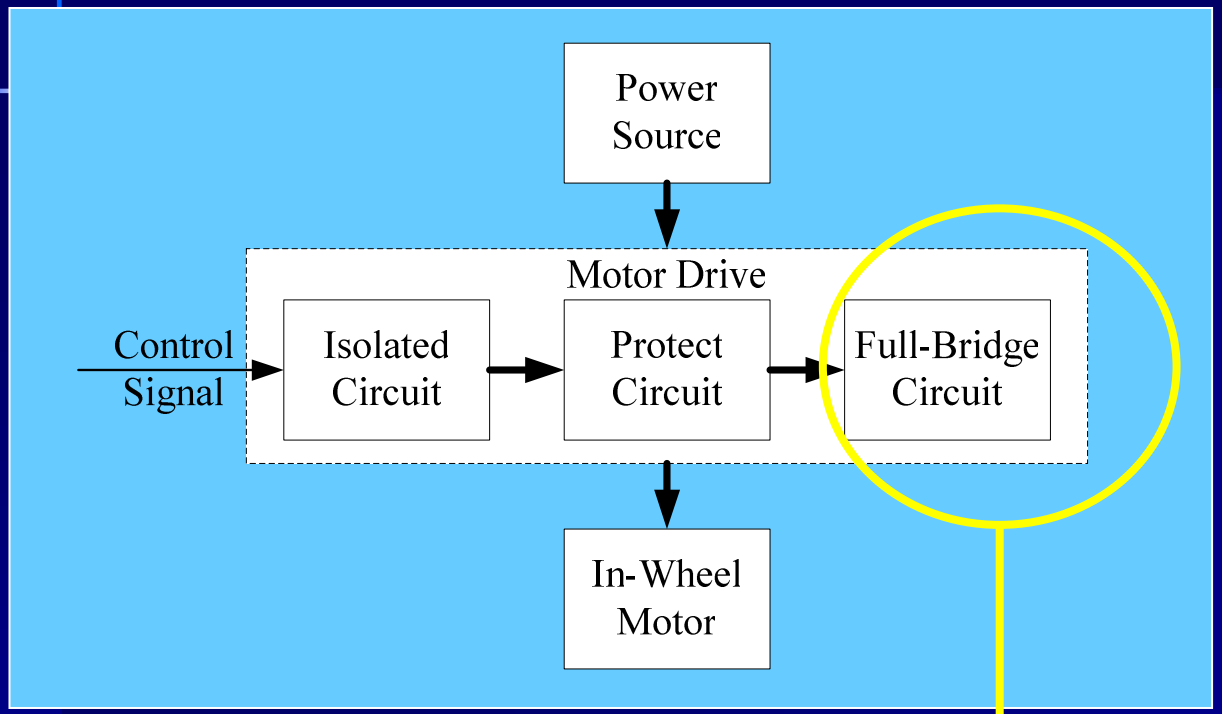


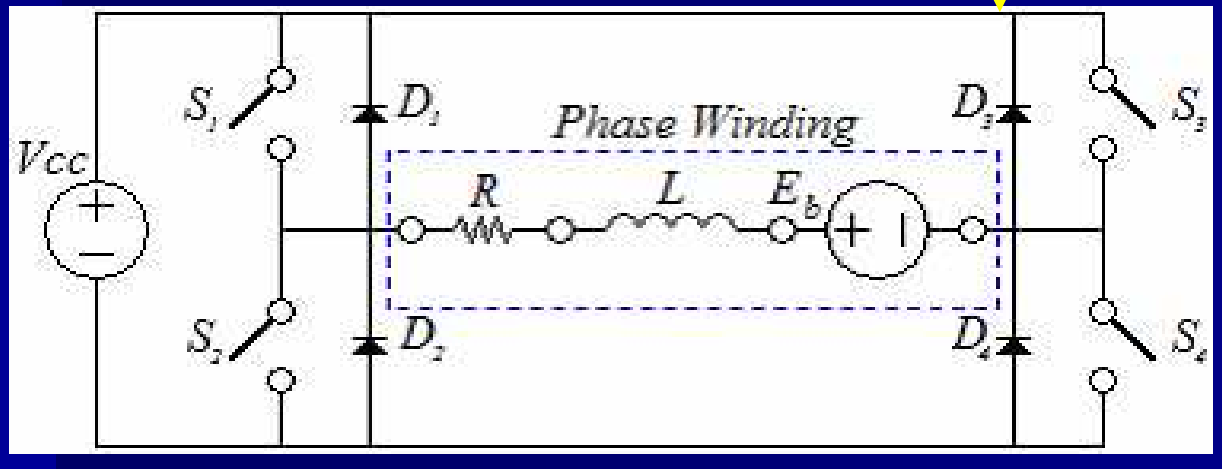
16 teeth stator



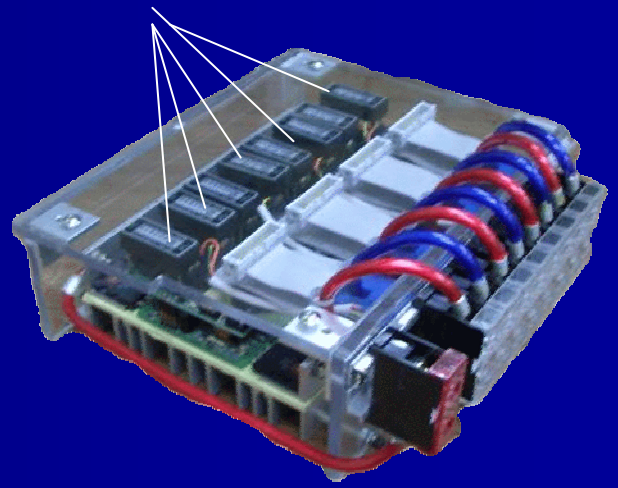
12 magnet rotor

Motor drive and power converter

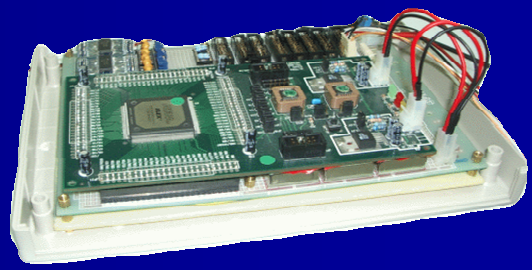




MOSFETs



Efficiency: 95%



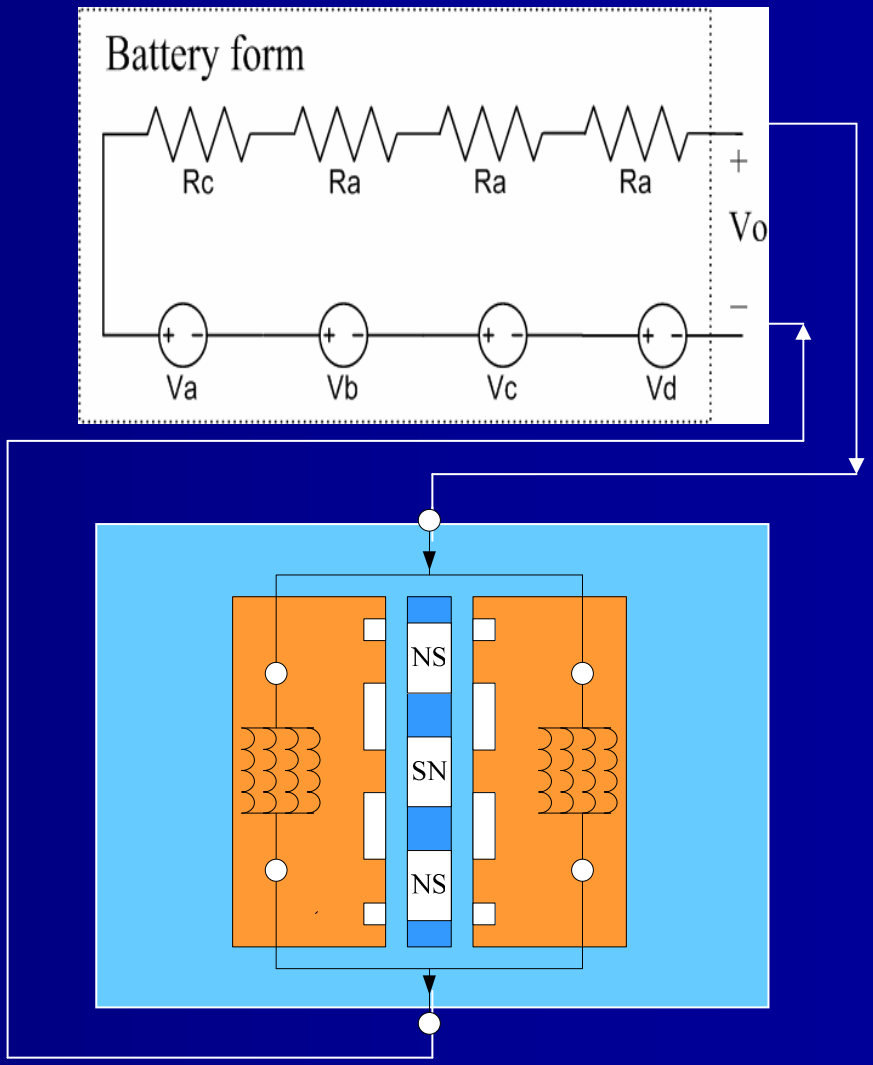
FPGA

Energy management system:

power source, electronic gearshift, & regenerative braking

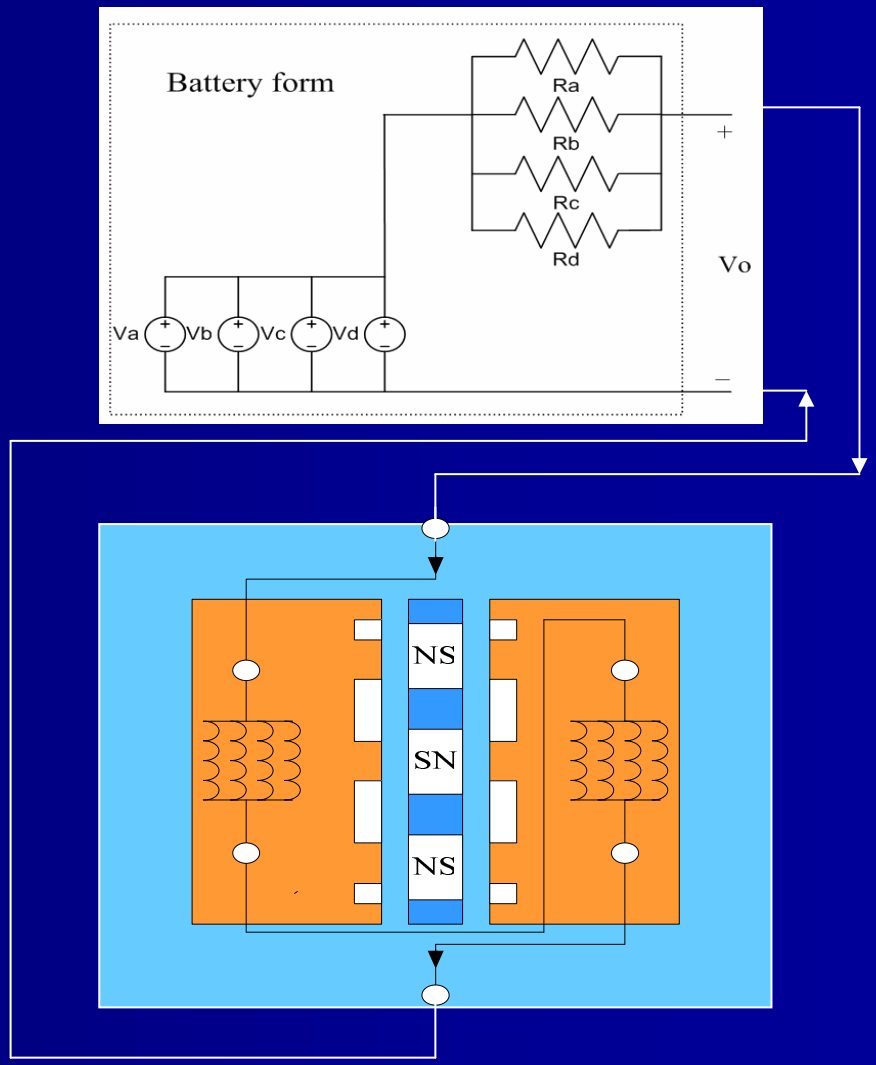
Scenario of Electronic Gearshift

- high-speed and low-torque operation:
  - Cruising mode
  - batteries are connected in series
  - stator windings are connected in parallel

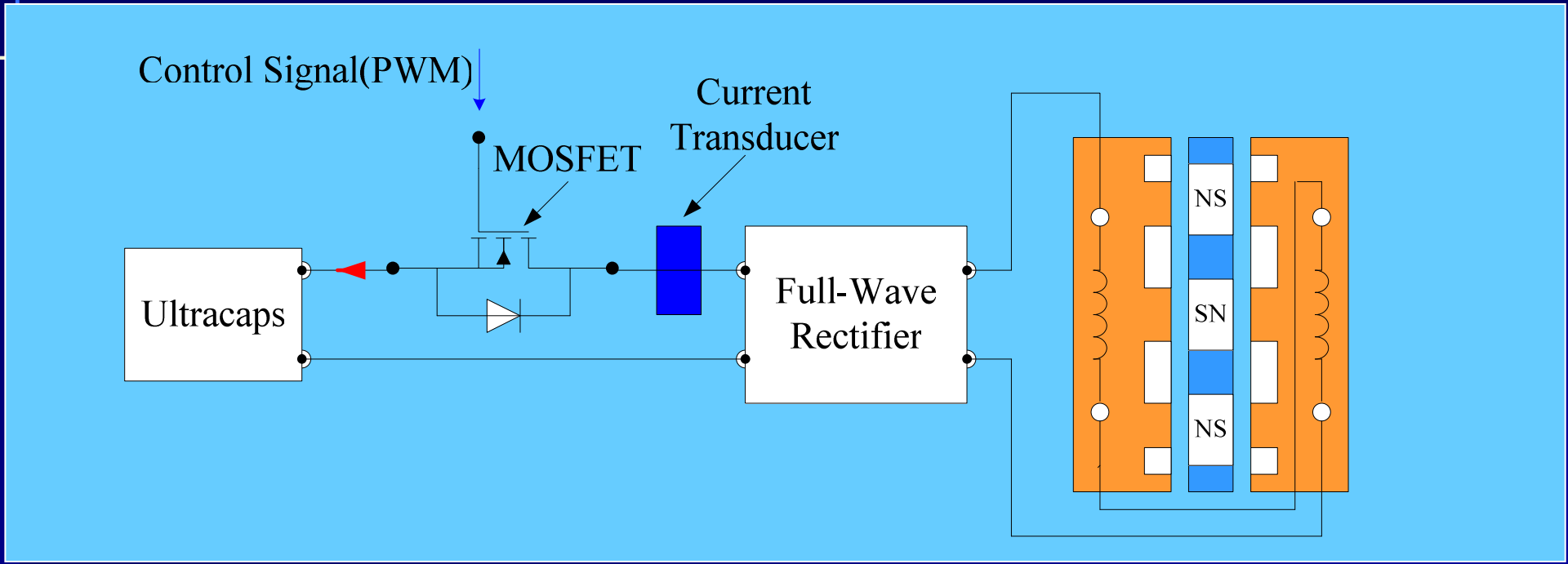


Scenario of Electronic Gearshift

- low-speed and high-torque operation:
  - Start-up and acceleration modes
  - Batteries are connected in parallel
  - Stator windings are connected in series

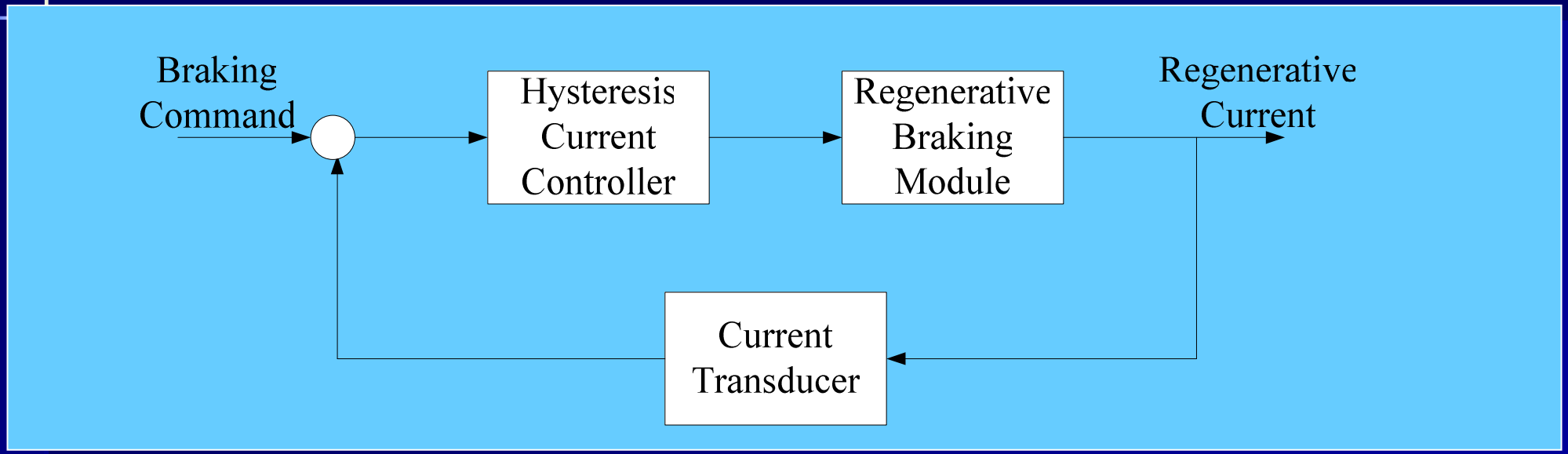


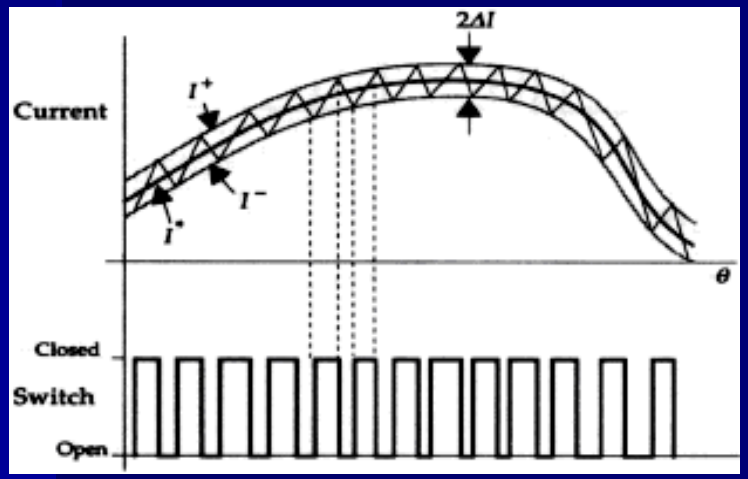
Usage of ultracapacitor



- to start up with impulsive current for acceleration
- to absorb regenerative braking power with high charging efficiency

Idea of regenerative braking current control

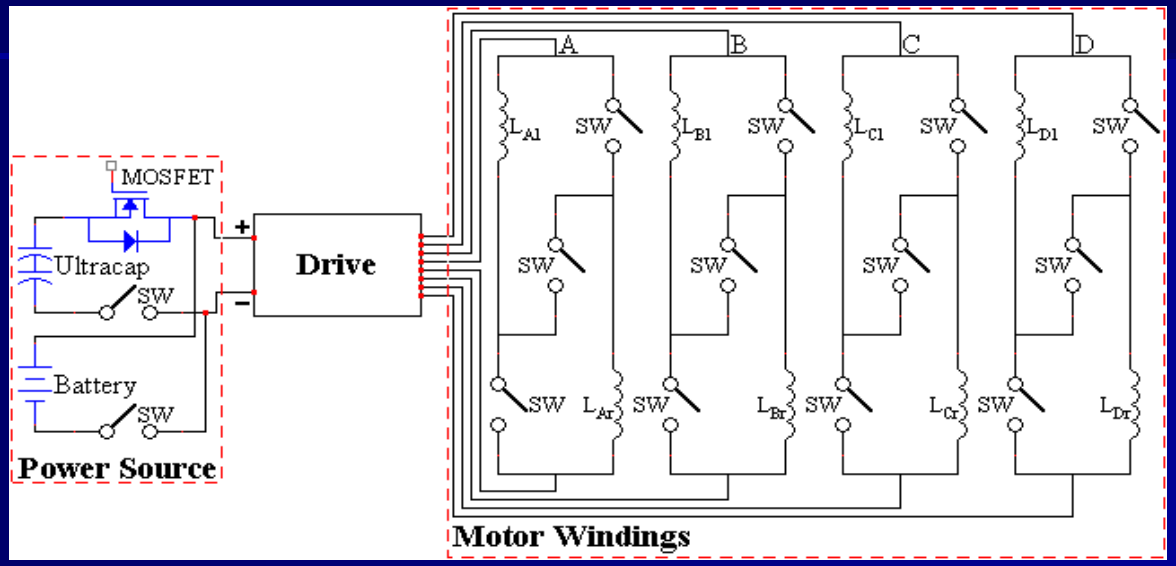




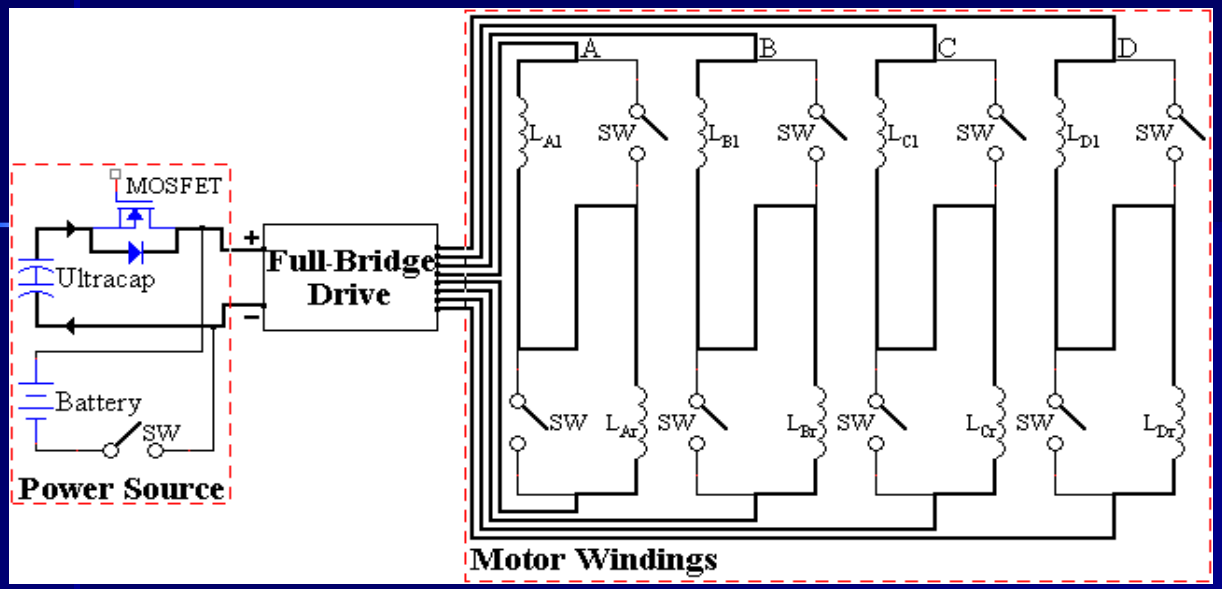
- **Overvoltage by serial stator winding**
- **Comfortable deceleration**

Braking command → PWM signal → switch MOSFETs → moderate current →ultracapacitor

Electronic Gearshift



State	Gear	Battery	Ultracap.	Winding
Driving	1	N/A	27V	Series
	2	48V	N/A	Series
	3	48V	N/A	Parallel
Braking	Continuous Variable	N/A	27V	Series

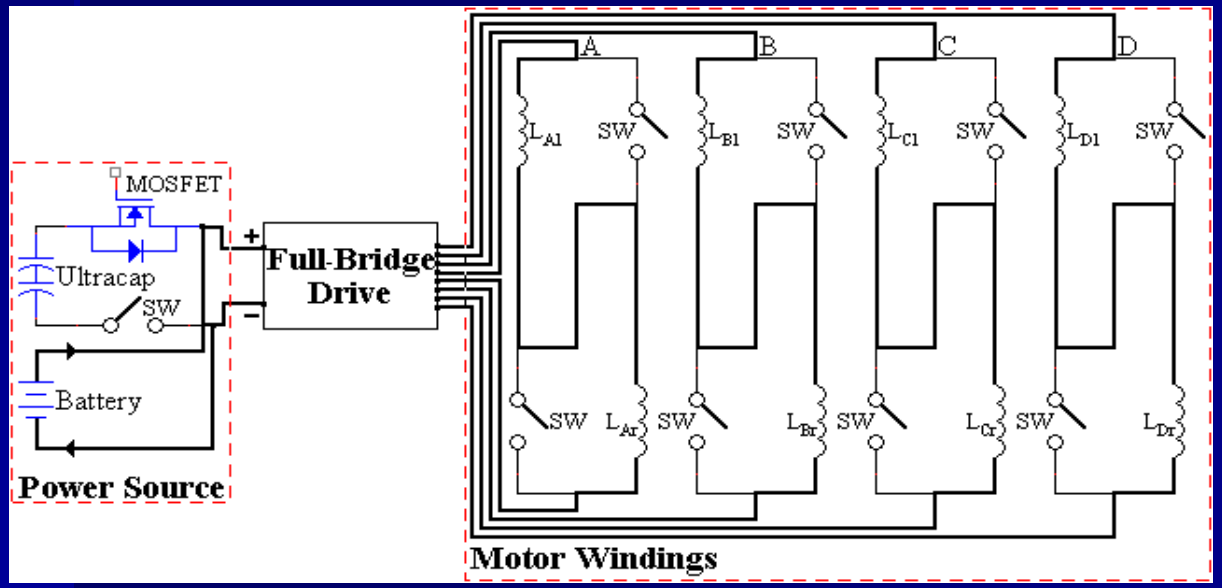


Gear 1

Ultracap

Serial winding

Start-up and acceleration

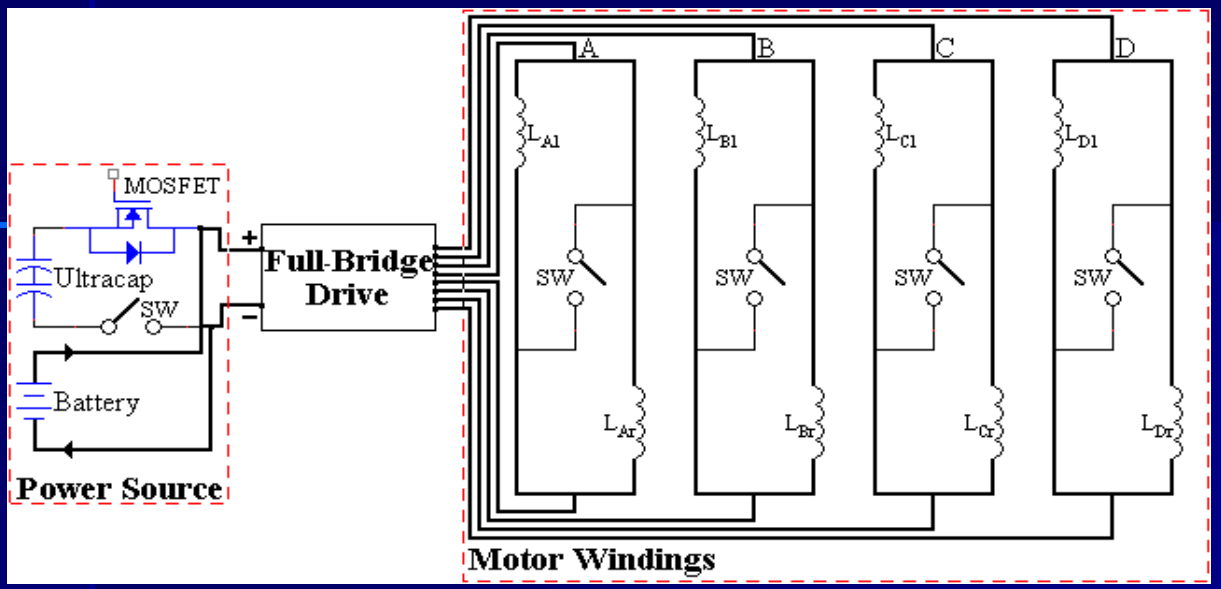


Gear 2

Battery

Serial winding

Cruising

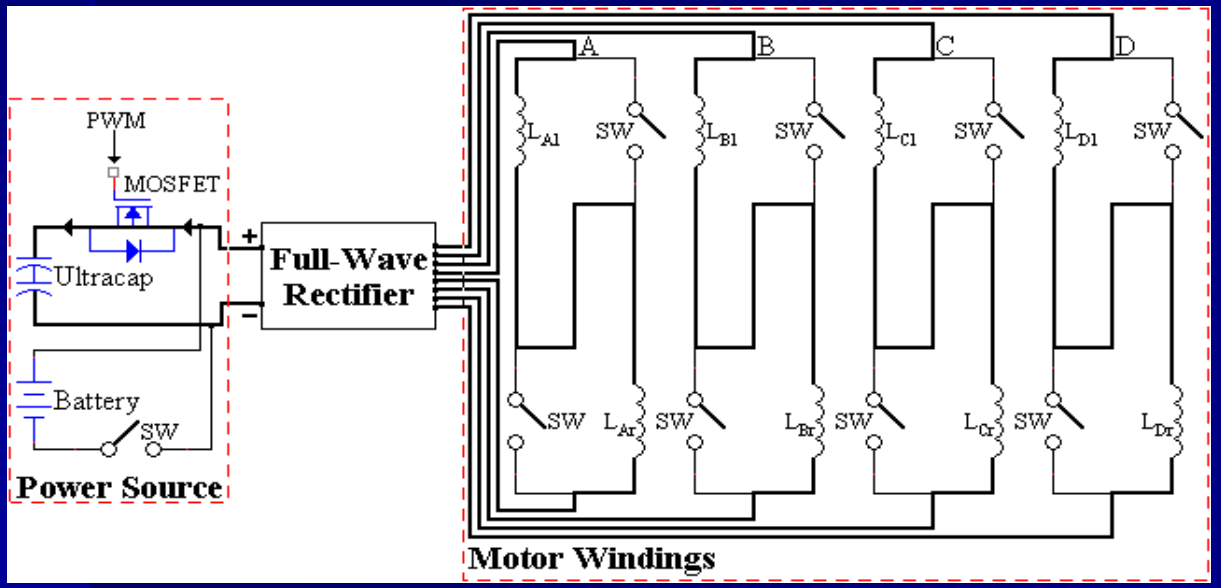


Gear 3

Battery

Parallel windings

Extend vehicle speed



Gear 4

Regenerative Braking

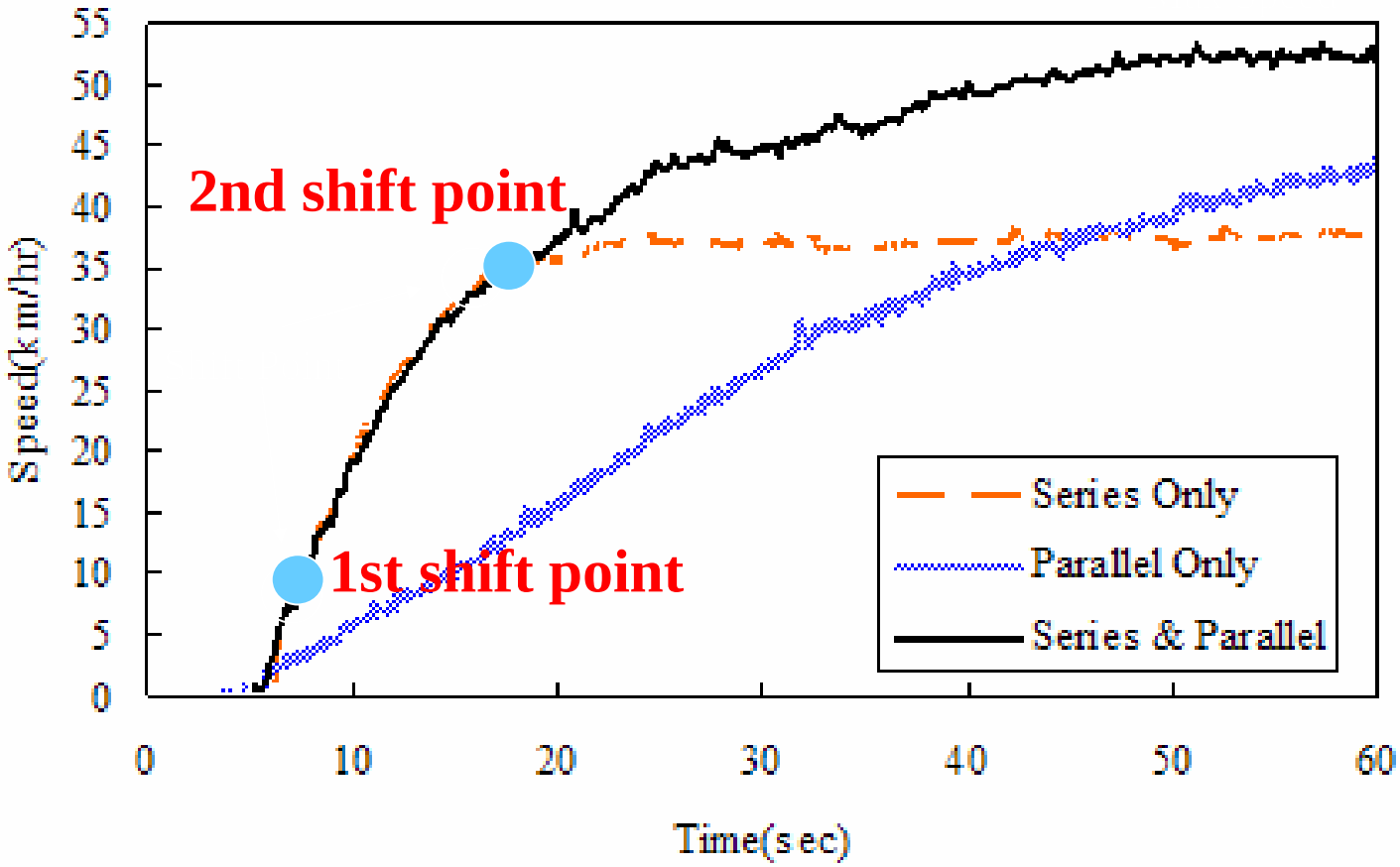
Ultracap

Serial windings

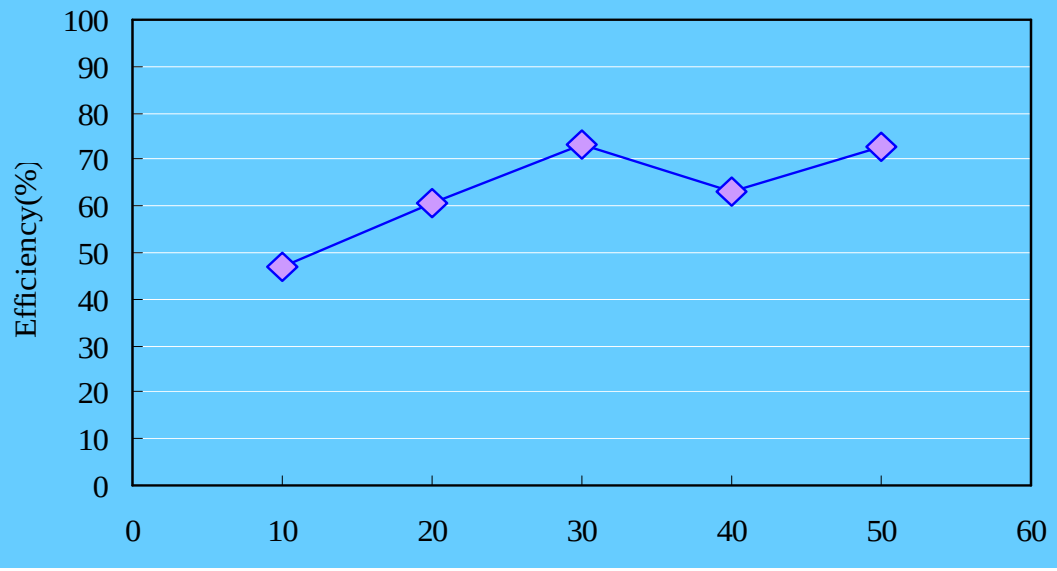
Restore elec. power

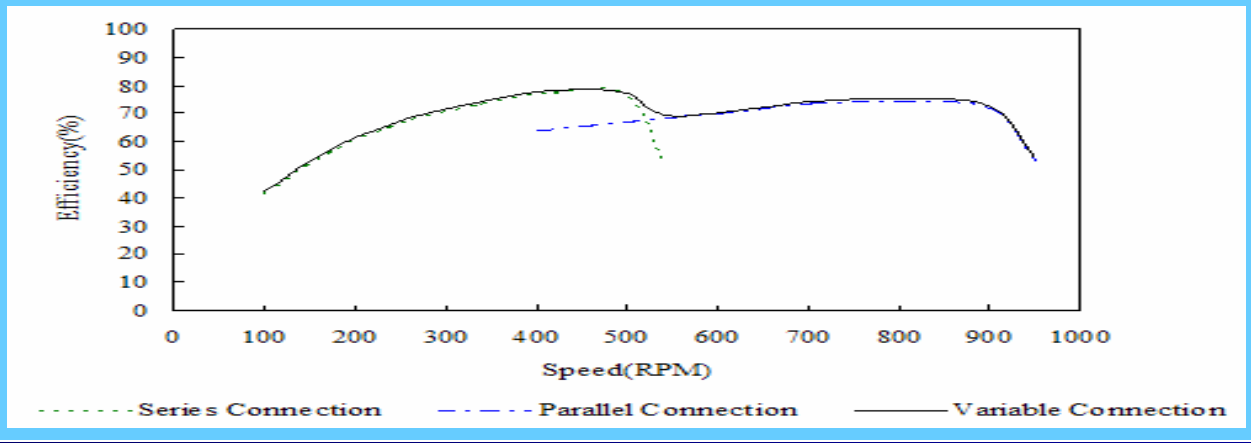
The second author 胡聰賢 on the road

Acceleration test



Constant Speed Efficiency Test (battery to wheel efficiency)

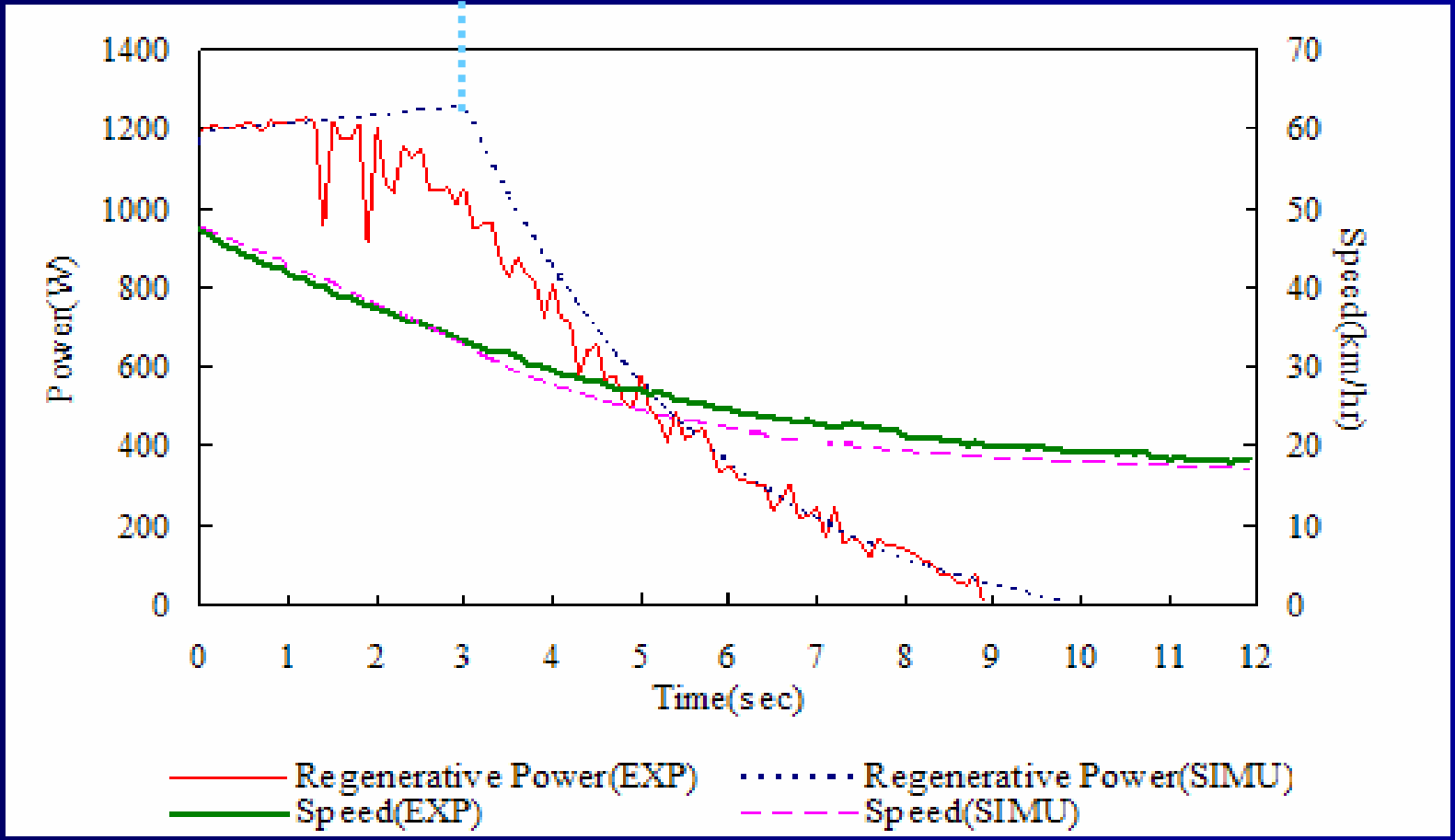




Regenerative Braking Test

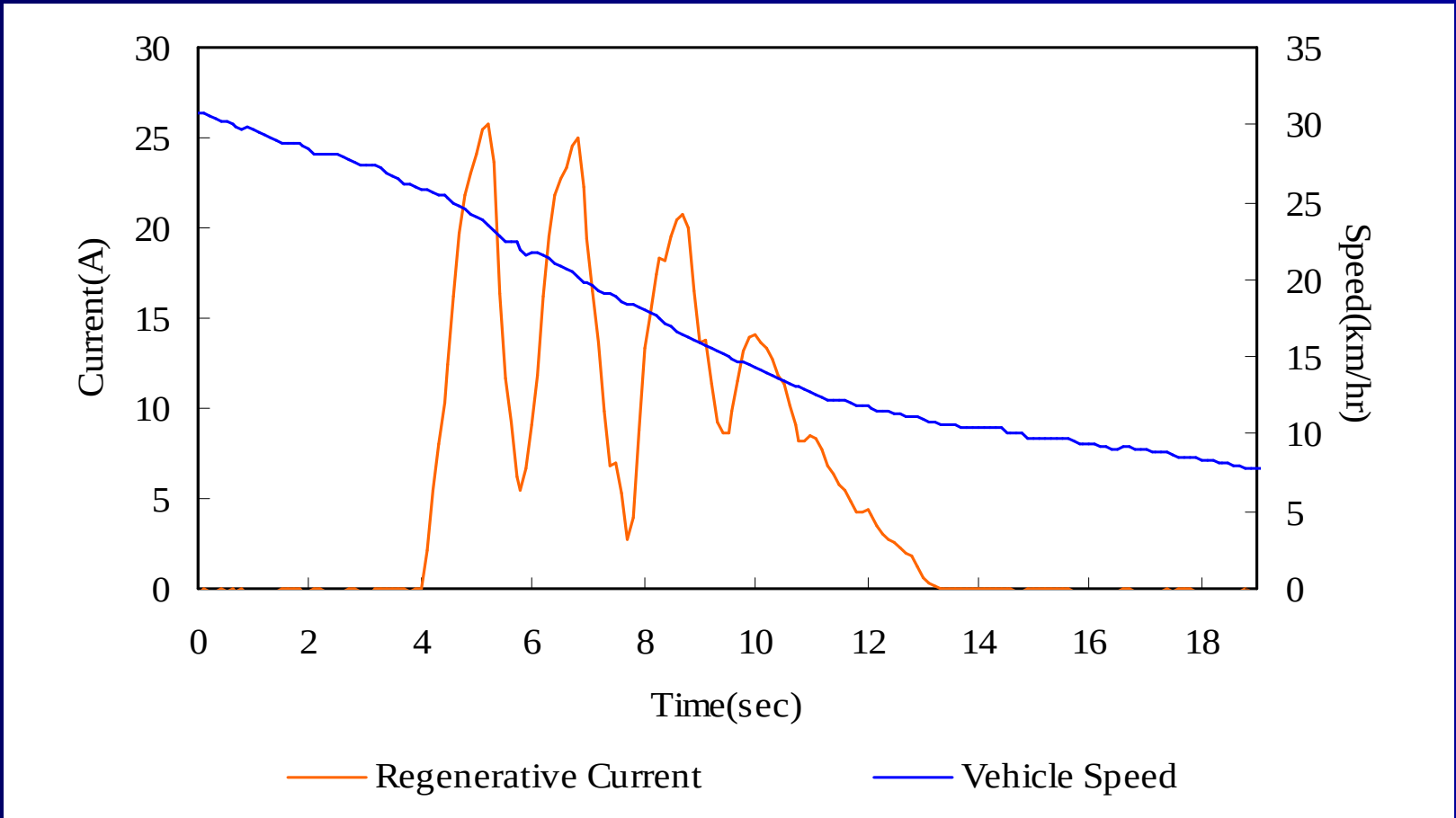
$V_{back} > I R$ | $V_{back} > I R$

I=50A | I < 50A

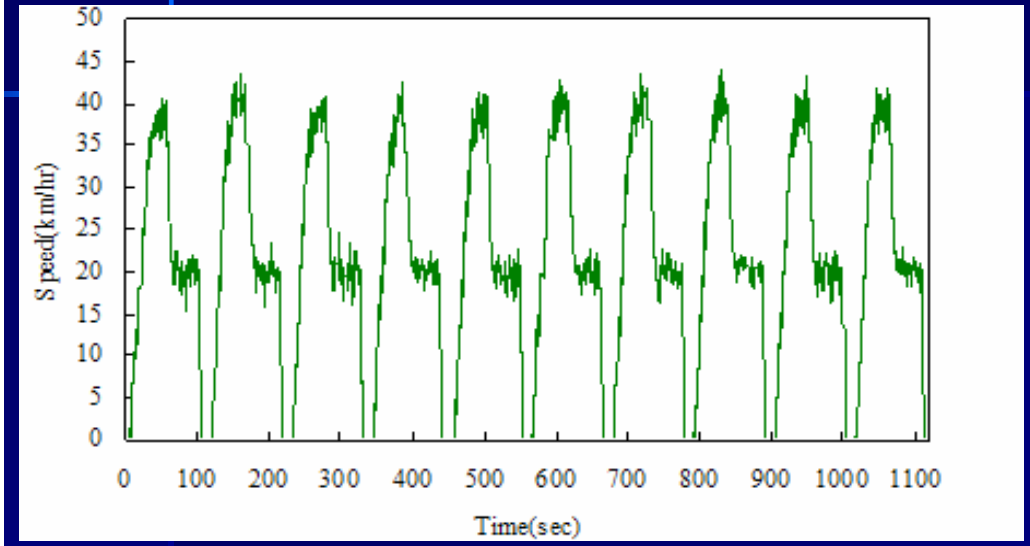


Exp → 5956J Simu → 6407J Error → 7.5%

Inconstant regenerative current and vehicle speed



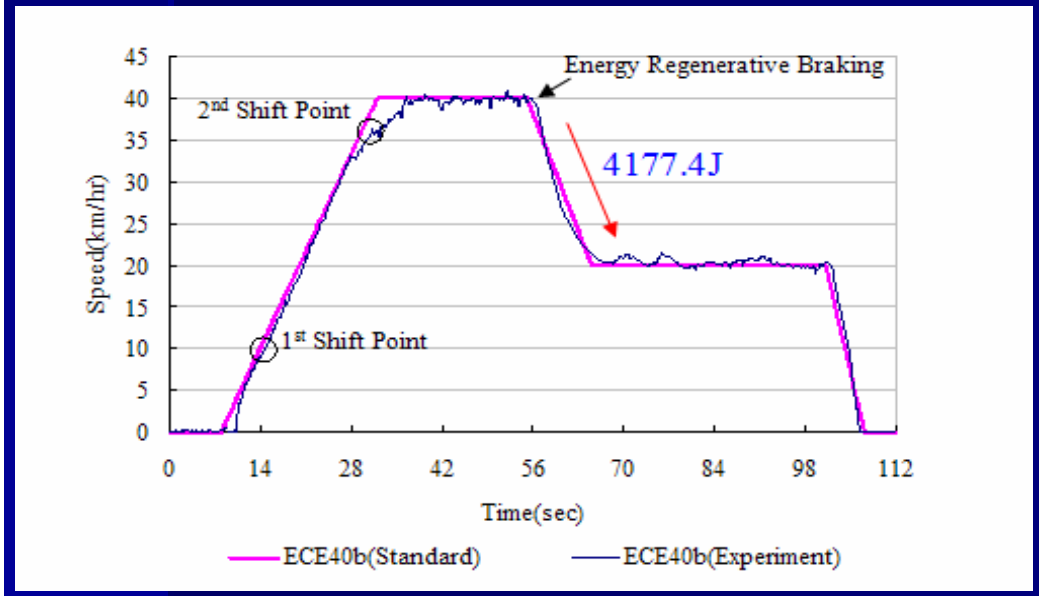
ECE47 driving range test



Total Kinetic Energy	8796.3J
Rolling Resistance loss	1552.7J
Aerodynamics loss	1686.8J
Regenerative Energy	4445.3J

Exp. 4177.4J Simu. 4445.3J

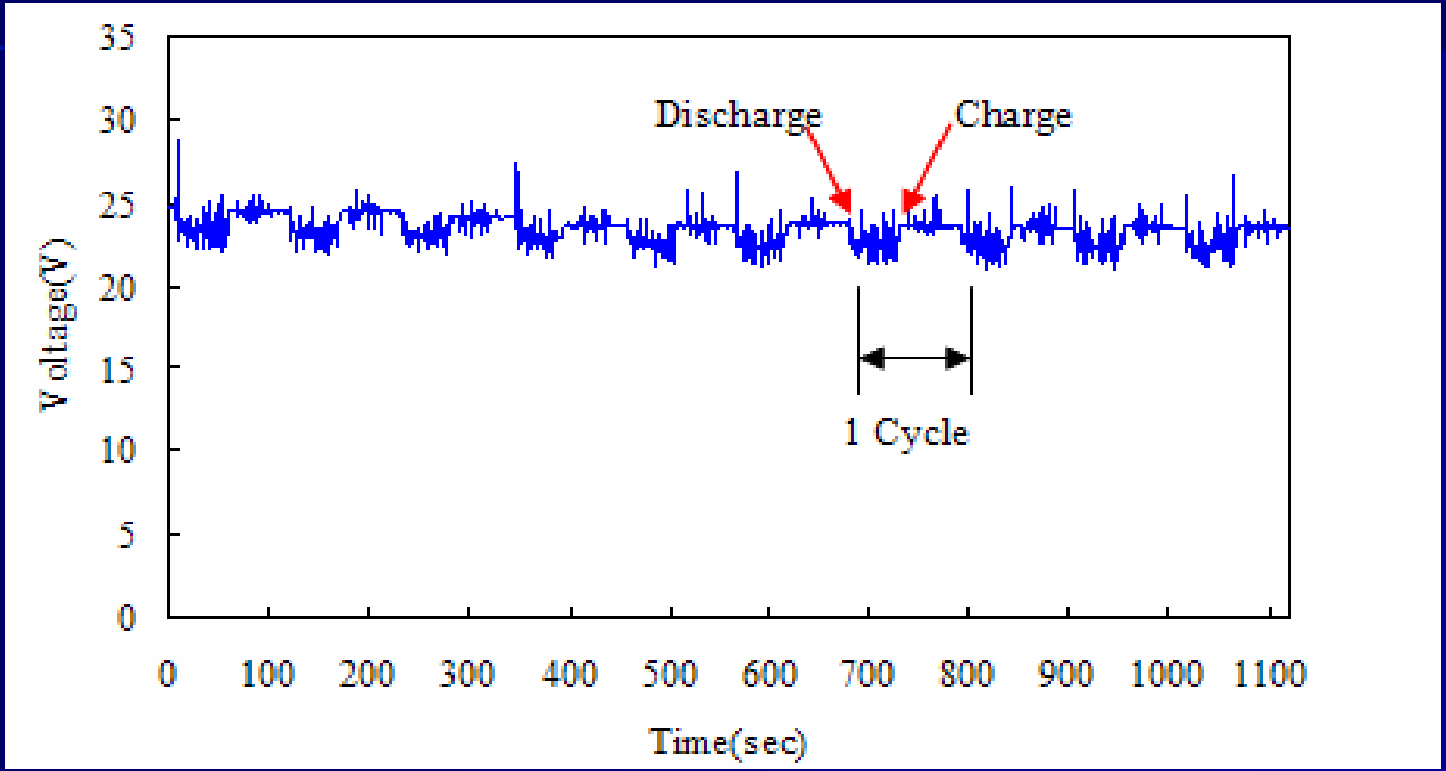
Error ➔ 6.4%



Regenerative energy rate: 75.2%

=(restored energy/kinetic energy)

Ultracap usage efficiency

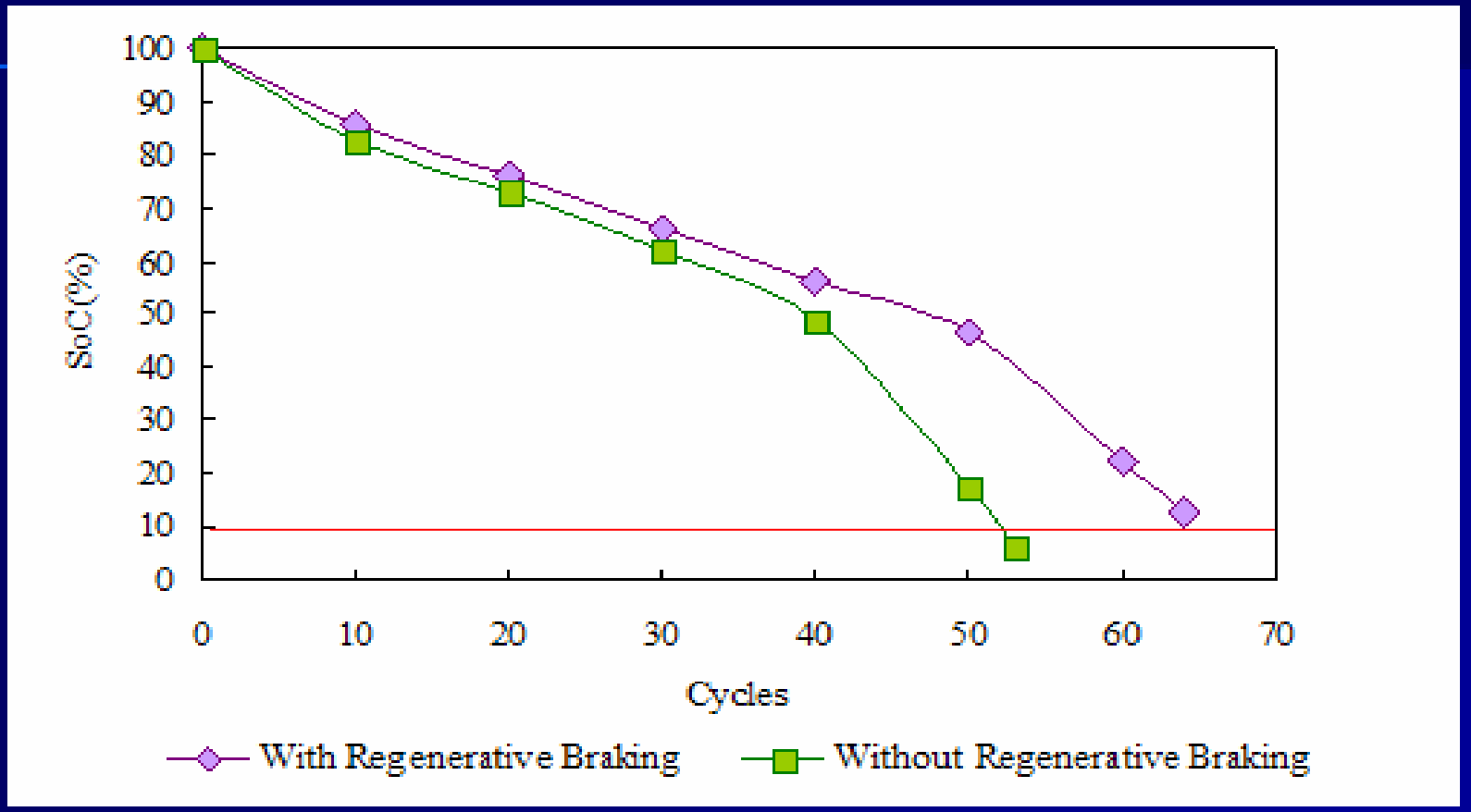


Gross discharged energy ➔ 232,016J

Net energy restored ➔ 226,255J

Usage rate ➔ 97.5%

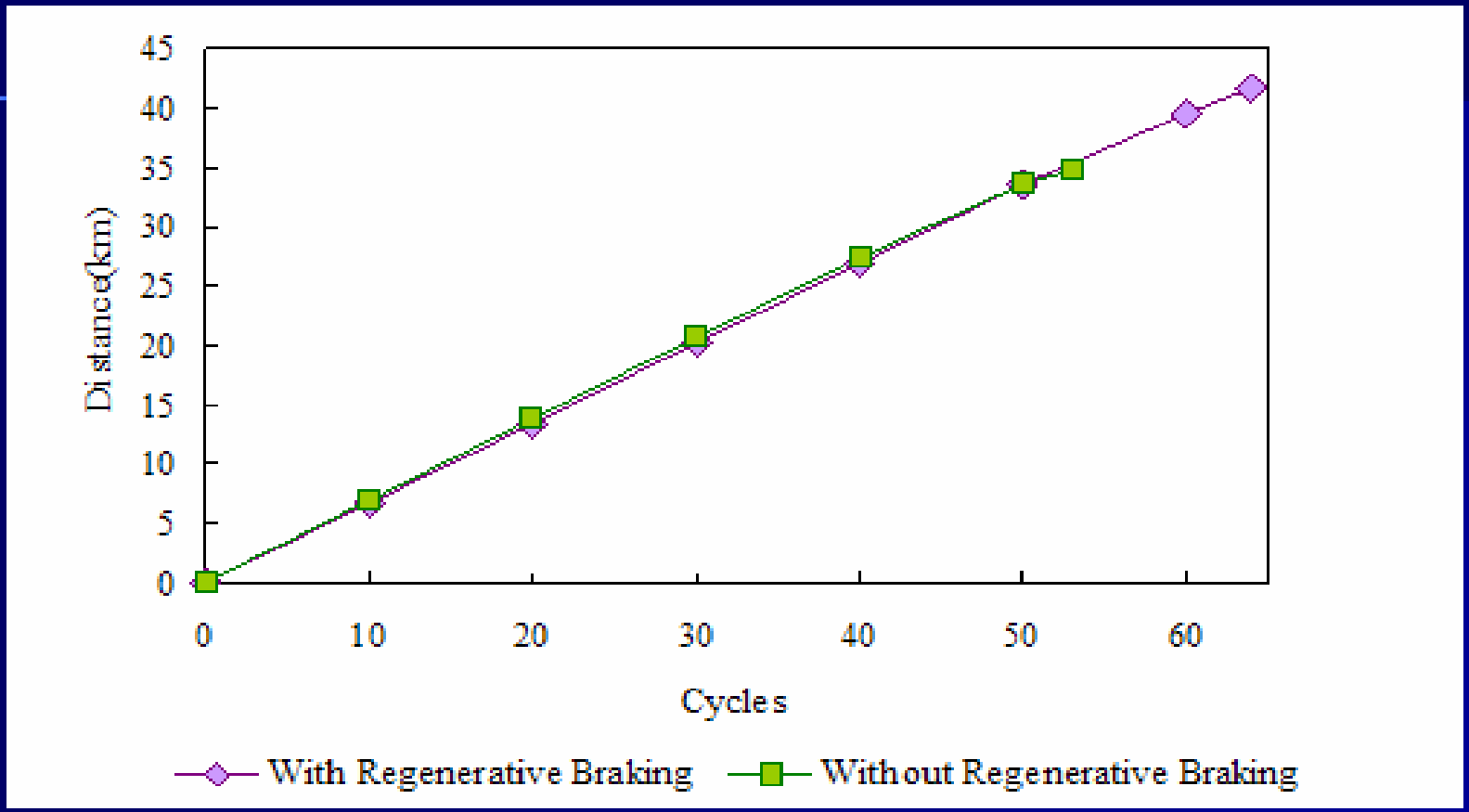
Battery usage rate



Without Regenerative Braking System ➔ 53 ECE47 cycles

With Regenerative Braking System ➔ 64 ECE47 cycles

Driving range test



Without Regenerative Braking System ➔ 34.7 km

With Regenerative Braking System ➔ 41.7 km

Net increased range 7 km (20%)

Road Test

Lab fellow 廖碩鯤 on the test

Conclusion

- A new energy management system features
  - Directly-driven wheel motor
  - Electronic gearshift
  - Regenerative braking with ultracapacitor
- Results:
  - Battery efficiency: 45% (controlled by supplier)
  - Motor-to-wheel efficiency: over 70% (at 30Km/hr)
  - Driving range increase: 20%
  - Lifetime of battery: prolonged

Thank you for your attention!