# Electric Drive Optimization

Chong Chee Kang

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# PMBLDC

- Permanent Magnet Brushless DC motor

Figure: PMBLDC motor, source: http://dev.emcelettronica.com/

# Shell Eco-Marathon

- Race for mileage, not speed
- Category:
  - Urban Concept
  - Protoype
- plug-in electric
- 4 laps with 10 seconds stoppage between each lap

# Problems

- Types of torque produced by PMBLDC
  - cogging torque
  - reluctance torque
  - mutual torque
- Torque ripple
- Poor Strategy

# Objectives

1. To identify the output signal of the controller circuit and the hall effect sensor of the PMBLDC and develop a set of instrument for measuring the mileage of the electric vehicle.
2. To study the track profile of Sepang North Track and create a simulation program for simulating the vehicle dynamics at the Sepang North Track.
3. To compose a set of strategy to increase the mileage of the electric vehicle running on the Sepang North Track using the simulation program.

# Methodology

# Signal Identification and Measurement System


Figure: Eclimo's speedometer

# Signal Identification and Measurement System

Figure: Scooterputer, source: http://www.janspace.com/b2evolution/arduino.php/scooterputer

# Signal Identification and Measurement System

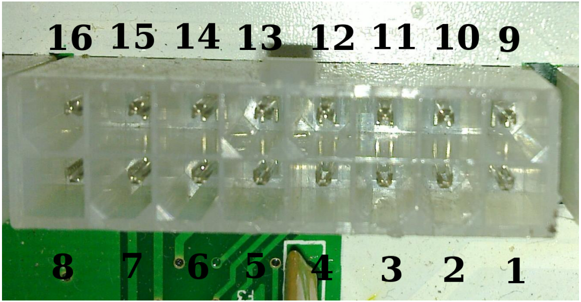



Figure: Controller 16 pin output

# Signal Identification and Measurement System

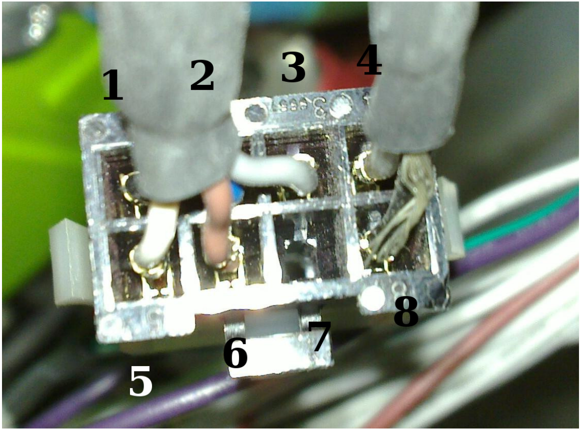



Figure: 8 pin hall effect sensors input/output

# Why Vehicle Simulation?

- Baseline data
- Strategies creation tool
- Study effect of a component
- Proprietary electric motor and controller

# Components

- Track
- Electric Motor
- Vehicle Dynamics

# Sepang North Track

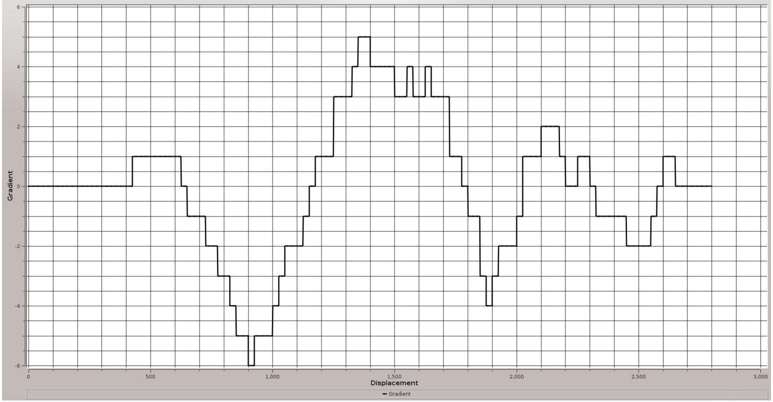



Figure: Sepang North Track gradient graph

# Electric Motor

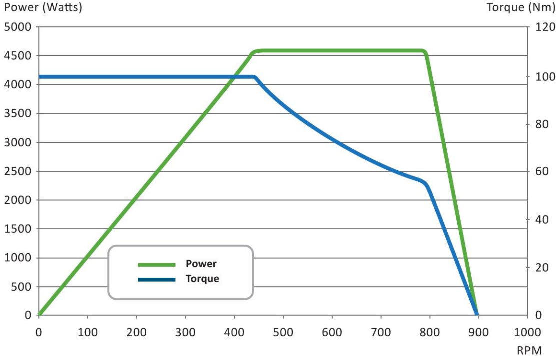



Figure: Torque and power output curve of KLD D1064R, source: KLD

# Electric Motor

$$T = \begin{cases} 100N.m, & \text{for (0 - 440 RPM)} \\ [0.0003(RPM)^2 - 0.493(RPM) + 260]N.m, & \text{for (441 - 800 RPM)} \\ [-0.56(RPM) + 504]N.m, & \text{for (801 - 900 RPM)} \end{cases} \tag{1}$$

# Vehicle Dynamics

- Air drag

$$F_{drag} = \frac{1}{2}\rho C_d A v^2 \tag{2}$$

- Rolling resistance

$$F_{roll} = mgC_{rr} \tag{3}$$

- Uphill/Downhill

$$F_{slope} = mgsin\theta \tag{4}$$

# Vehicle Dynamics

- Combined

$$\sum F_{resistance} = mgsin\theta + mgC_{rr} + \frac{1}{2}\rho C_d A v^2 \tag{5}$$

- Vehicle acceleration

$$a = \frac{(\frac{\tau}{R} - \sum F_{resistance})}{m} \tag{6}$$

# Result

# Speed Signal

| Voltage Probe | Ground Probe | Voltage |
|---|---|---|
| 2 | 1 | -56.6 |
| 3 | 1 | -44.2 |
| 4 | 1 | 0.0 |
| 5 | 1 | -55.9 |
| 6 | 1 | -56.6 |
| 7 | 1 | 0.0 |
| 8 | 1 | 0.0 |
| 9 | 1 | -33.4 |
| 10 | 1 | -33.4 |
| 11 | 1 | -56.6 |
| 12 | 1 | -28.3 |
| 13 | 1 | -24.0 |
| 14 | 1 | -23.3 |
| 15 | 1 | -21.1 |
| 16 | 1 | -23.7 |

Table: Result of signal tapping with the ground probe on pin 1 and voltage terminal on pin 2 to pin 16.

# Speed Signal

| Voltage Probe | Ground Probe | Voltage |
|---|---|---|
| 1 | 2 | 56.8 |
| 3 | 2 | 12.4 |
| 4 | 2 | 0.0 |
| 5 | 2 | 0.0 |
| 6 | 2 | 0.0 |
| 7 | 2 | 0.0 |
| 8 | 2 | 0.0 |
| 9 | 2 | 22.6 |
| 10 | 2 | 22.6 |
| 11 | 2 | 0.0 |
| 12 | 2 | 29.9 |
| 13 | 2 | 0.0 |
| 14 | 2 | 0.0 |
| 15 | 2 | 0.0 |
| 16 | 2 | 0.0 |

Table: Result of signal tapping with the ground probe on pin 2 and voltage terminal on pin 1, pin 3 to pin 16.

# Speed Signal

| Voltage Probe | Ground Probe | Voltage |
|---|---|---|
| 1 | 2 | 56.7 |
| 3 | 2 | 12.4 |
| 4 | 2 | 0.0 |
| 5 | 2 | -3.4 |
| 6 | 2 | 0.0 |
| 7 | 2 | 0.7-2.4 |
| 8 | 2 | 0.7-3.2 |
| 9 | 2 | 22.6 |
| 10 | 2 | 22.6 |
| 11 | 2 | 0.0 |
| 12 | 2 | 27.8 |
| 13 | 2 | 0.0 |
| 14 | 2 | 0.0 |
| 15 | 2 | 0.0 |
| 16 | 2 | 0.0 |

Table: Result of signal tapping with the ground probe on pin 2 and voltage terminal on pin 1, pin 3 to pin 16 and the motor rotating.

# Speed Signal

- Pin 1: Battery voltage
- Pin 2, 6, 11: Ground
- Pin 3: 12V power supply
- Pin 5: Speed output signal

# Hall Effect Sensors Signal

| Voltage Probe | Ground Probe | Voltage |
|---|---|---|
| 1 | 8 | 10.4 |
| 2 | 8 | 10.4 |
| 3 | 8 | 10.4 |
| 4 | 8 | 3.1 |
| 5 | 8 | 0.2 |
| 6 | 8 | 0.1 |

Table: Result of hall effect sensors signal tapping with the ground probe on pin 8 and voltage terminal on pin 1 to pin 6.

# Hall Effect Sensors Signal

- Pin 2, 3, 5: Hall Effect Sensors output
- Pin 1: Power Supply
- Pin 8: Ground

# Measurement System

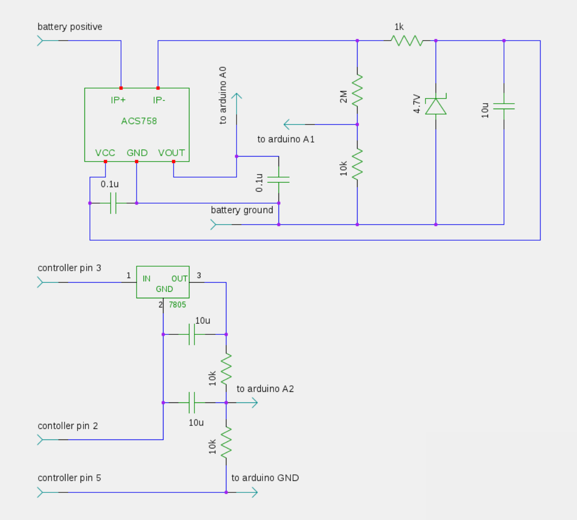



Figure: Schematic of the Measurement System

# Measurement System

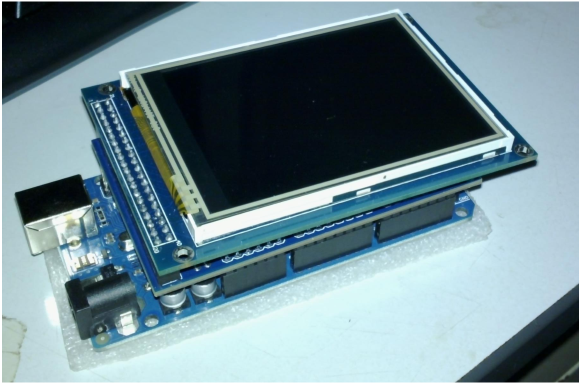


Figure: Arduino Microcontroller, display shield and LCD display

# Vehicle Simulation

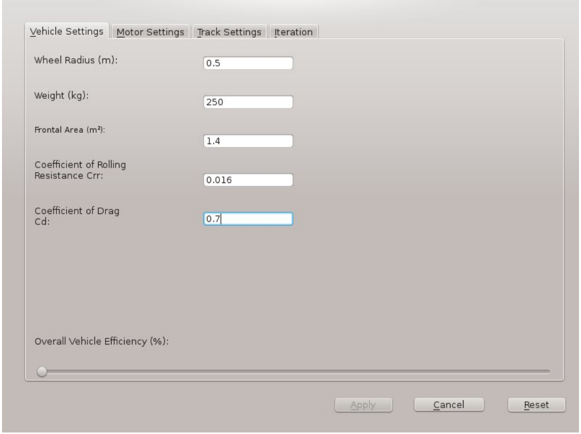



Figure: Vehicle parameter for initializing the vehicle model

# Vehicle Simulation

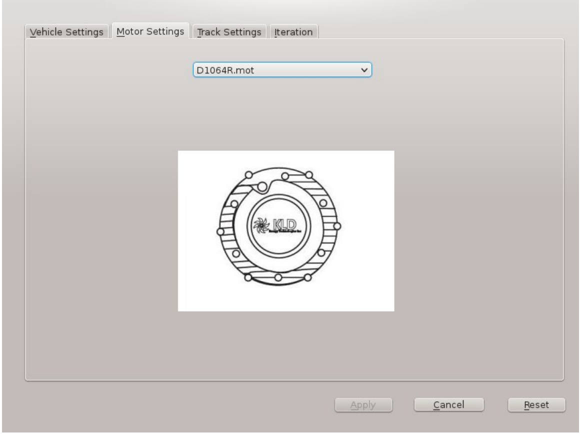



Figure: Choosing the motor model

# Vehicle Simulation

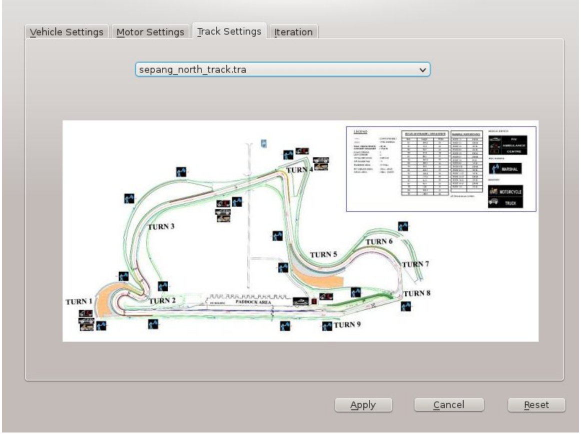



Figure: Choosing the track model

# Vehicle Simulation

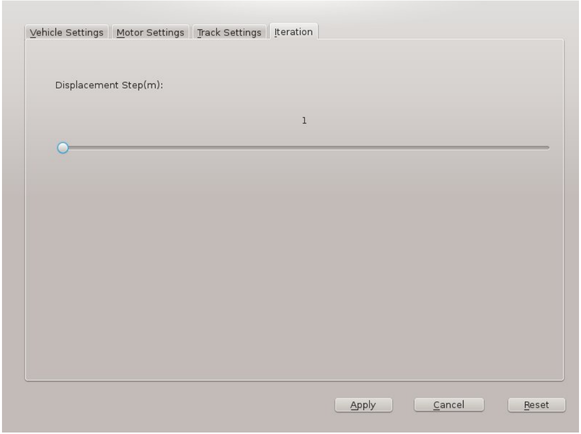



Figure: Setting the displacement interval for iteration

# Vehicle Simulation

| Parameter | Value |
|---|---|
| Wheel Radius | 0.5 m |
| Total Vehicle Mass | 250 kg |
| Frontal Area | 1.4 $m^2$ |
| Crr | 0.016 |
| Cd | 0.7 |

Table: Parameters for building the electric vehicle model

# Strategies

1. Full Throttle Everywhere
2. Preset Strategy 1
3. Preset Strategy 2
4. Preset Strategy 3

# Full Throttle Everywhere

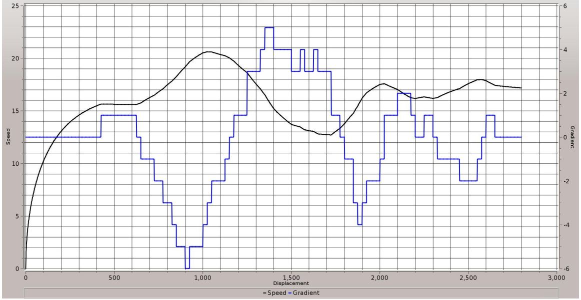



Figure: Graph of speed and gradient versus displacement for "full throttle everywhere"

# Full Throttle Everywhere

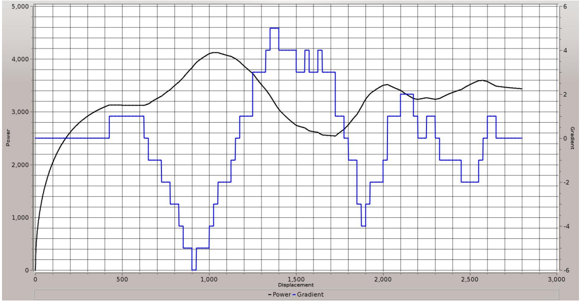



Figure: Graph of power and gradient versus displacement for "full throttle everywhere"

# Preset Strategy 1

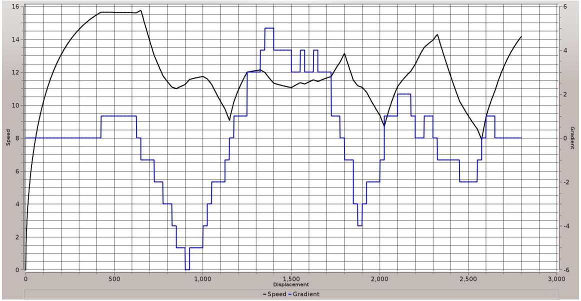



Figure: Graph of Speed and Gradient versus displacement for "Preset Strategy 1"

# Preset Strategy 1

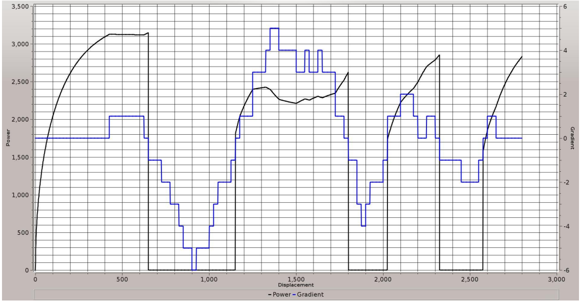



Figure: Graph of Power and Gradient versus displacement for "Preset Strategy 1"

# Preset Strategy 2

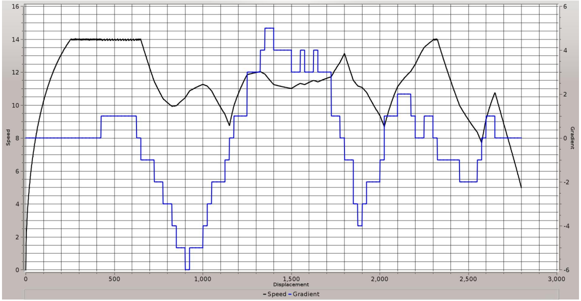



Figure: Graph of Speed and Gradient versus displacement for "Preset Strategy 2"

# Preset Strategy 2

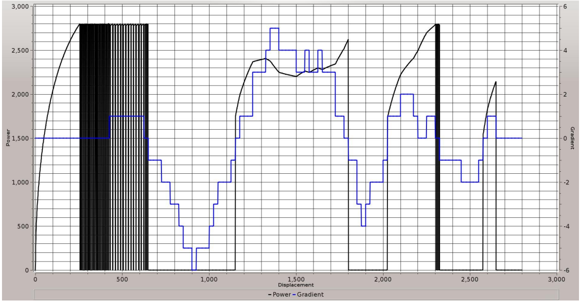



Figure: Graph of Power and Gradient versus displacement for "Preset Strategy 2"

# Preset Strategy 3

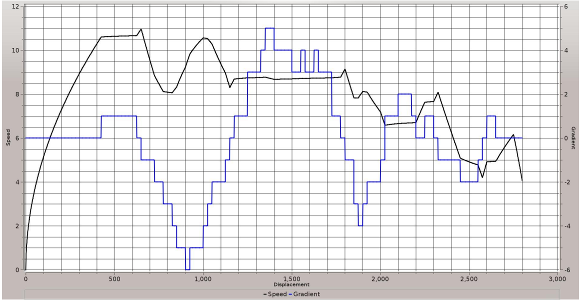



Figure: Graph of Speed and Gradient versus displacement for "Preset Strategy 3"

# Preset Strategy 3

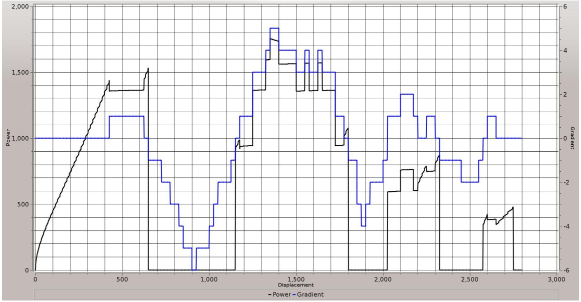



Figure: Graph of Power and Gradient versus displacement for "Preset Strategy 3"

# Comparison Between Strategies

| Result | FTE | PS1 | PS2 | PS3 |
|---|---|---|---|---|
| Total Energy Consumption | 560003J | 365004J | 318200J | 216385J |
| Lap TIme | 186.981s | 246.554s | 261.699s | 390.491s |
| Mileage | 18.0 km/kWh | 27.6 km/kWh | 31.7 km/kWh | 46.6 km/kWh |

Table: Result comparison for various strategies

# Comparison Between Strategies

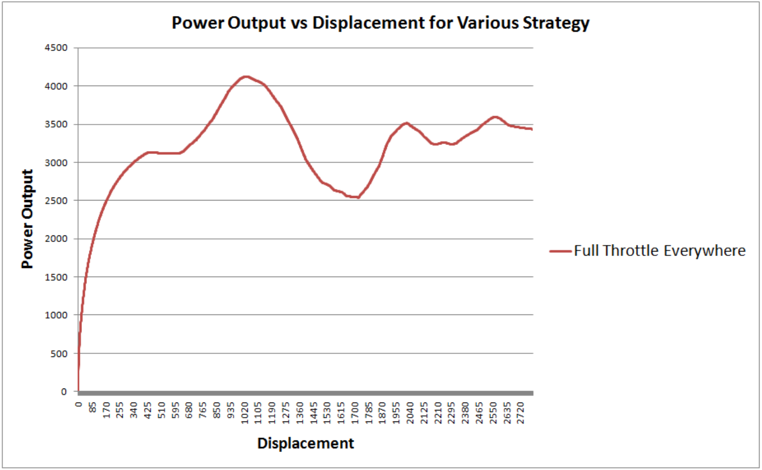
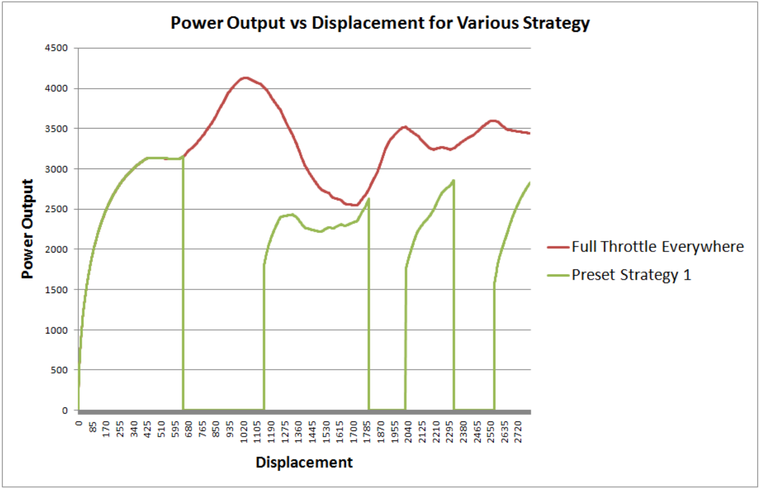



Figure: Graph of power output versus displacement for various strategy

# Comparison Between Strategies

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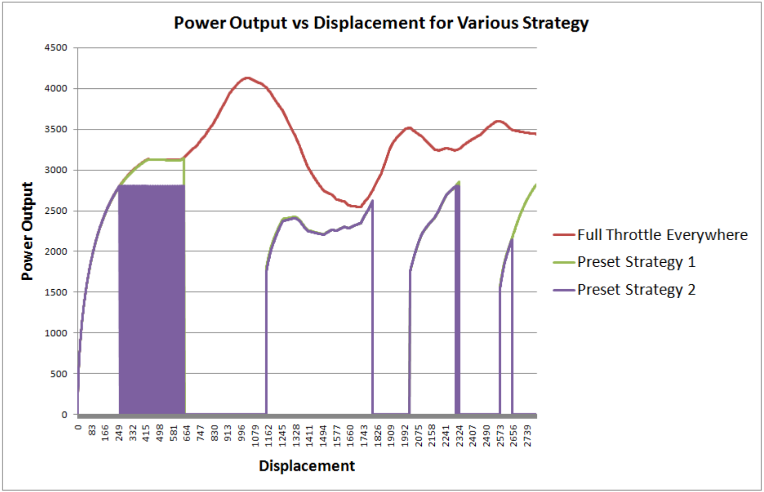


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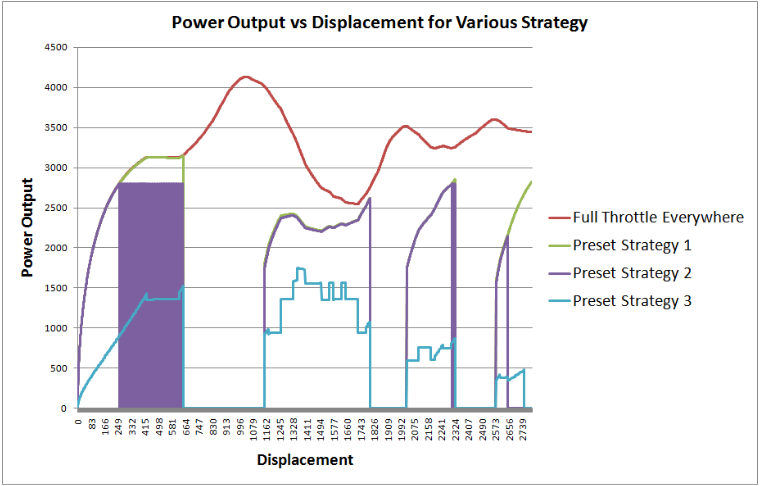


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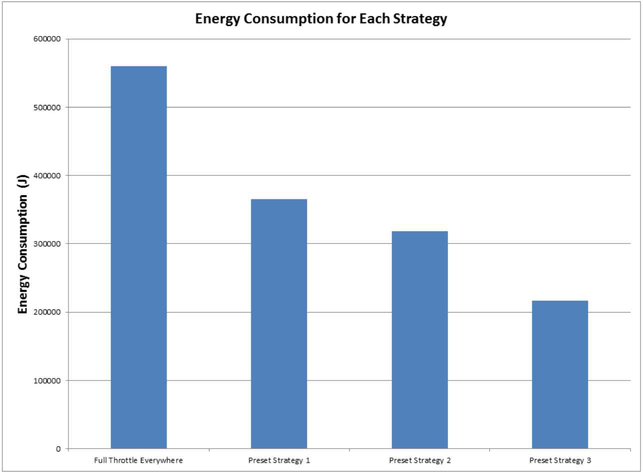


Figure: Graph of energy consumption for each strategy

# Comparison Between Strategies

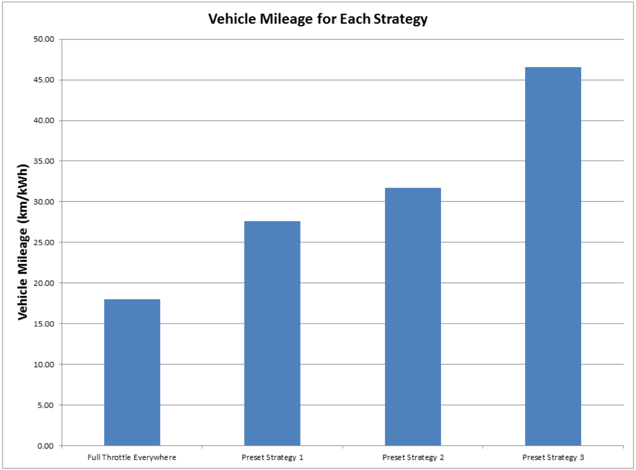


Figure: Graph of vehicle mileage for each strategy

# Comparison Between Strategies

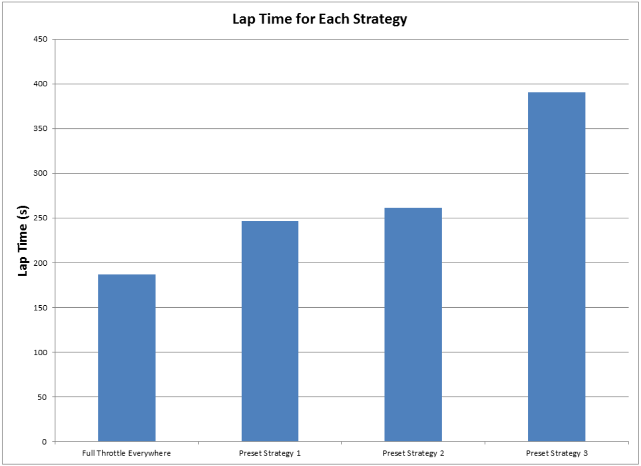


Figure: Graph of lap time for each strategy

# Conclusion

1. To identify the output signal of the controller circuit and the hall effect sensor of the PMBLDC and develop a set of instrument for measuring the mileage of the electric vehicle. **(Achieved)**
2. To study the track profile of Sepang North Track and create a simulation program for simulating the vehicle dynamics at the Sepang North Track. **(Achieved)**
3. To compose a set of strategy to increase the mileage of the electric vehicle running on the Sepang North Track using the simulation program. **(Achieved)**

# Future Work

1. hall effect sensor signal - controller phase current
2. improve Coefficient of Drag
3. improve vehicle simulation software

Q&A

Thank you