MODELING AND ANALYSIS PERFORMANCE OF BLDC MOTOR (ELECTRIC BICYCLE)

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UNIVERSITI MALAYSIA PAHANG

MODELING AND ANALYSIS PERFORMANCE OF BLDC MOTOR ELECTRIC BICYCLE

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This thesis is submitted as partial fulfilment of the requirements for the award of the Bachelor of Electrical Engineering (Hons.) (Power Systems)

Faculty of Electrical & Electronics Engineering
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ABSTRACT

This project is about modeling and analysis of the technical performance of BLDC motor for e-bike whereas it will discuss about the modelling of a direct drive BLDC motor electric bicycle drive system for technical performance evaluation. A hardware called Cycle Analyst had been use to investigate the instantaneous drive parameters such as voltage, current, power and speed of the electric bicycle. The Cycle Analyst V3 measures and displays information about the battery, acts as a general-purpose trip computer, rec-ords and calculates vehicle and rider performance statistics, monitors and displays data from optional input devices, and operates or limits the mo-tor controller based on the monitored and calculated data. The Cycle Analyst come from different manufacturer of the controller set. In this project, its need to integrate with the existing controller of the electric bicycle. Besides, a simulation of rider performance from usual bicycle will be shown by using software called AnyBody.

ABSTRAK

Projek ini melibatkan pemodelan dan analisis prestasi teknikal BLDC motor untuk e-basikal sedangkan ia akan membincangkan tentang pemodelan sistem pemanduan basikal elektrik BLDC motor memandu langsung untuk penilaian prestasi teknikal. Satu perkakasan dipanggil Cycle Analyst telah digunakan untuk menyiasat parameter pemanduan terus seperti voltan, arus, kuasa dan kelajuan basikal elektrik. Cycle Analyst V3 mengira dan memaparkan maklumat mengenai bateri, bertindak sebagai komputer perjalanan kegunaan umum, rekod dan mengira statistik kenderaan dan prestasi penunggang, memaparkan data dari peranti input pilihan, dan mengendalikan atau menghadkan pengawal motor berdasarkan data dipantau dan dikira. Kitaran Analyst datang dari pengeluar yang berbeza set pengawal. Dalam projek ini, Cycle Analyst perlu diintegrasikan dengan pengawal yang sedia ada basikal elektrik. Selain itu, simulasi penunggang dari basikal biasa akan ditunjukkan dengan menggunakan perisian ANYBODY.

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LIST OF SYMBOLS

V	Voltage
A	Ampere
W	Watt
Km/h	Kilometer per hour
Min	Minimum
Max	Maximum
Ave	Average
Ah	Ampere hours
S+	Shunt Positive
S-	Shunt Negative
Gnd	Ground
P_e	Electrical Power
P_m	Mechanical Power
e_a	Trapezoidal Back EMF for Phase a
e_b	Trapezoidal Back EMF for Phase b
e_c	Trapezoidal Back EMF for Phase c
T_e	Electromagnectic Torque
T_L	Load Torque
J	Inertia
B	Damping factor
ω_r	Angular Speed
I_{max}	Maximum current

LIST OF ABBREVIATIONS

BLDC	Brushless Direct Current
CA V3	Cycle Analyst Version 3
DC	Direct Current
E-Bike	Electric Bicycle
EMF	Electrical Magnetic Field
EV	Electrical Vehicle
PAS	Pedal Assist System
PEDE-LEC	Pedal Electric Cycle

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Nowaday the electric vehicle (EV) has been developed so much consist of electronic motor, battery and charger replace the engine, gasoline pump and tank of the conventional gasoline-powered [1]. In other word, instead of using man power or fuel to move the vehicle, in this case use battery to make it move. The development of electric vehicle triggered due to the lack of fuel and pollutions [2].

BLDC motor was used in various type of motor because of their advantages. Some of the advantages are BLDC have a greater speed capabilities, higher efficiency, high torque to inertia ratio, better thermal efficiency and lack of noise. Brushless DC motors have many benefits over their brushed DC motor counterparts. The clear benefits of a brushless motor is its lack of brushes and physical commutator. This difference means that many fewer parts that can break or wear out and need to be replaced than in a brushed motor. A BLDC motors tend become more reliable, last longer, and be more efficient. In fact, BLDC motors have lifetime more than 10,000 hours [3].

The Brushless Direct Current (BLDC) motor rapidly gaining popularity by its utilization in various industries such as appliances, automotive, consumer, medical, industrial automation equipment , aerospace, and instrumentation. The name implies, the BLDC motors do not have to use brushes for commutation; instead, they are electronically commutated. The BLDC motors have many advantages over brushed DC motors and induction motors [4]. One of the famous application of BLDC motor is electric bicycle.

Electric bicycle is a bicycle with integrated electric motor which can be used for propulsion. Electric bicycle motor assists the rider using a pedal-assist system or by a power-on-demand. It also can be classified to 3 major groups which are electric bicycle with pedal-assist only, electric bicycles with power-on-demand and pedal-assist and lastly electric bicycles with power-on-demand only. The definition of pedal assist is electric motor regulated by pedaling. It equips with “Pedelec”, a sensor to detect the pedaling speed and the pedaling force. Besides, the definition of power-on-demand is the electric motor is activated by a throttle [15].

1.2 PROBLEM STATEMENT

In order to utilized BLDC motor as the propeller for EV, immense researches on every element of BLDC motor driver have to be done. The current controller e-bike does not have any display of drive parameter the motor current, voltage, speed and power. Thus, a hardware is needed to use to monitor the drive parameter. Furthermore, physiological properties of the rider body and the e-bike properties affected the comfort of the rider. Hence, ergonomic optimization of the rider will simulate in ANYBODY to show rider's interaction with the e-bike.

1.3 OBJECTIVES

The objectives of this project

1. To integrate CA V3 with current controller which display various instantaneous drive parameter such as motor current, voltage, power and speed.
2. To simulate of rider ergonomic performance by ANYBODY software.

1.4 PROJECT SCOPES

In order to accomplish the objectives of this project, there are three scopes that have been taken. This include of the studying the literature review about BLDC motor, integrate and customize the hardware, modelling and simulate rider profile by using ANYBODY software.

First, the literature review of the project. This is an important part to do as long as to understand more about the motor system, and the characteristic of the motor especially in BLDC motor. The source of the knowledge could be found via internet, journals, magazines, articles, books *etc.*

Secondly, the integration and customize hardware. The CA V3 needs to be integrate with e-bike controller in order to monitor and display various instantaneous drive parameter of the motor of the e-bike.

Lastly, the analysis and simulation would be performed by using ANYBODY simulation software. This will perform the characteristic of the rider muscle ergonomic performance based on bicycle and rider characteristic such as height and mass.

1.5 THESIS STRUCTURE

Chapter 1: Introduction

This chapter describe the introduction to the brushless dc motor drive system and is contribution as many kinds of the industrial application. This chapter also provide some explanations about problem statement, objectives and scope of this project.

Chapter 2: Literature Reviews

Literature review contained all the basic information about brushless dc motor, electric bicycle, Cycle Analyst and ANYBODY simulation. These include of the overview of the brushless dc motor and information about the ANYBODY simulation also will also been discussed.

Chapter 3: Methodology

In this chapter, the method that have been used for this project will present in detailed. This chapter will be discussing on the flow of the project from the very beginning until the system is complete. Begin with literature review and supervisor advise, the knowledge was used and applied to the modelling and analysis of the technical performance of the e-bike. The output from the technical performance will be analyzed and lastly, conclusion and recommendation been made.

Chapter 4: Result and Analysis

In this chapter, various instantaneous drive parameter of the e-bike was monitored on the Cycle Analyst are the current, voltage, input power, and speed. The parameter gain from the Cycle Analyst are the input parameter fed to the motor. The output parameter such as torque, RPM and mechanical power was gain from dyno testing where the e-bike was run on the chassis dyno meter. Both result later been analyzed and compared

Chapter 5: Conclusions and Recommendations

Lastly, chapter 5 will concluded the work based on the result and discussion firm this project and suggested some recommendation for future work improvement and development for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The goal of this chapter is to provide a past research review efforts related to modeling and analysis the performance of Brushless DC (BLDC) motor for electric bicycle. Some articles discuss on the importance of BLDC in electric bicycle technical performance while the other discuss about BLDC motor application, e bike controller and software used.

2.2 BRUSHLESS DC (BLDC) MOTOR

Brushless DC motor has been used on many electrical application in this world. One of them is Electric Bicycle. The BLDC (brushless DC) motor is characterized by linear torque to current and speed to voltage. It has fast dynamic response and low acoustic noise. Moreover, it has high power density with high proportion of torque to inertia in spite of small size drive. However, at high-speed operation, torque and speed response characteristic is deteriorated by the motor inductance components in stator windings [5]. Brushless DC motors have a permanent-magnet rotor, and the stator windings are wound such that the back electromotive force (EMF) is trapezoidal. It therefore requires rectangular-shaped stator phase currents to produce constant torque [6].

2.2.1 Operational BLDC motor

Figure 2.2 shows a BLDC Motor diagram. The rotor inside the BLDC motor with permanent magnet will rotate close to the Hall Effect Sensor. Then after the sensor get the signal, it will trigger the switch to switch on the inverter to control the current flow. Current will produce flux as it flows to the stator winding. Hence, induced voltage produced from the flux and rotate the rotor magnet. The speed of rotor increase or decrease and the output speed connected with the proportional plus integral (PI) controller to control the motor speed. The rotor continues to rotate until the speed or rotor achieve the speed of reference.

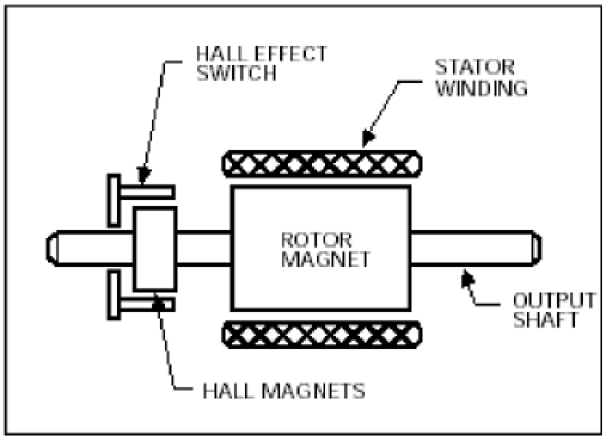

Figure 2.1. BLDC motor diagram [9]

2.2.2 Mathematical Modelling of BLDC Motor.

Typical BLDC motor has three stator and permanent magnets on the rotor. Since magnet and stainless steel retaining sleeves both have resistivity, rotor-induced current can be neglected and no damper windings are modeled [10].

The equation of electromagnetic torque:

$$T_e = \frac{(e_a i_a + e_b i_b + e_c i_c)}{\omega_r} \tag{2.1}$$

The interaction of T_e with the load torque determine how the motor speed builds up:

$$T_e = T_L + J\frac{d\omega_r}{dt} + B\omega_r \tag{2.2}$$

Where T_L is load torque, J is inertia, and B is damping.

Figure 2.2 shows a trapezoidal back EMF, current waveforms and position hall Effect sensor signal of three phase BLDC motor. To drive the motor with maximum and constant torque, the phase currents must be synchronized with the corresponding phase back EMF voltages. Moreover, at each mode only two phases are conducting and another phase is inactive

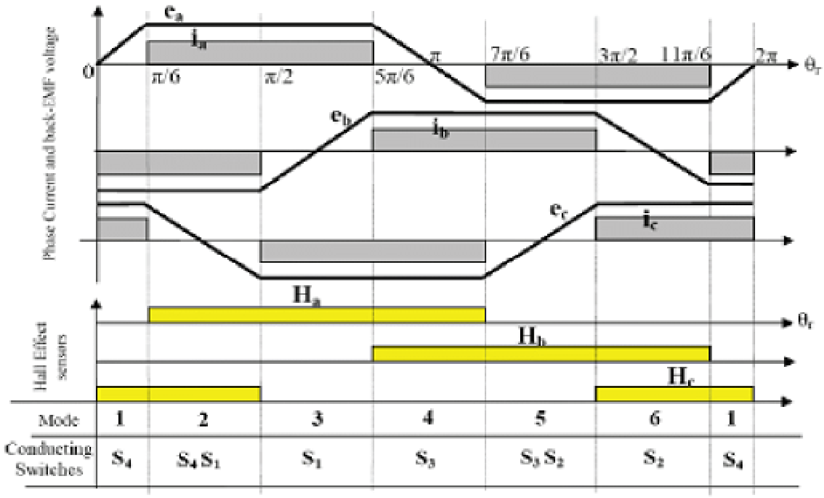

Figure 2.2. Back Current Waveform and EMF of BLDC motor [10]

As shown in Figure 2.2 the back EMF is function of position ofrotor. It has amplitude of $E = K_e \omega_r$ where K_e is a back EMF constant. Speed and torque characteristic of BLDC can be proved from equation above. Damping factor is assume neglected and the new equation arranged.

$$\omega_r = \frac{1}{J}\int (T_e - T_L)dt = \frac{1}{J}\int [(T_a + T_b + T_c) - T_L]dt \tag{2.3}$$

The relationship of current and torque:

$$P_e = EI_{max} = P_m = T_e \omega_r \tag{2.4}$$

Hence,

$$T_e = \frac{E}{\omega_r} I_{max} = K_t I_{max} \tag{2.5}$$

From the equation above, we can say that the torque, current and voltage (back EMF) have relationship with speed. As the conclusion, to control the speed of BLDC, we control voltage and current of the controller.

2.3 POSITION SENSOR

Operation of permanent magnet synchronous motor require position sensors in rotor shaft when operated without damper winding [11]. The knowledge of the position sensor for the BLDC motor is a major part to understand because it related to the inverter switching part and the brushless dc motor speed detection.

2.3.1 Hall Effect Sensor

Hall effect sensor is a transducer that varies its output voltage in response to change magnetic field. Hall sensors are used for proximity switching, positioning speed detection and current sensing application [12]. The permanent magnet rotor position must be specified only six times during electrical cycle for the inverter operation. Therefore, encoders and resolvers are least preferred especially due to their high cost and high volume. On the other hand, Hall sensors are mostly utilized since their cost is affordable and their structure is compact, they provide adequate information for rotor position [13].

2.3.2 Basic Operation of Hall Effect

When permanent magnet of the rotor gets close to the hall IC, the sensor sends a signal to the switching component inverter. The electromagnet pushes permanent magnet of rotor position sensor and the permanent magnet rotation.

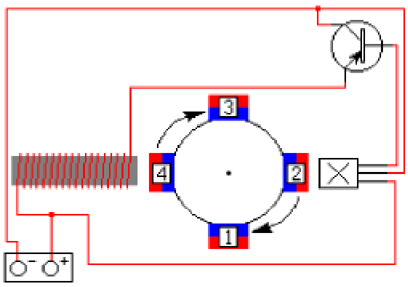

Figure 2.3. Basic diagram of permanent magnet rotation [13].

There are four main devices for measurement of the position, the potentiometer, linear variable differential transformer, resolvers and optical encoder. In order to knowing the rotor position requires the development of devices for position measurement. The application and performance desired depend to the motor position sensor with desired accuracy can be selected [11].

2.4 ELECTRICAL BICYCLE (E-Bike)

Electric bicycle, also known as an e-bike or booster bike, is a bicycle with an integrated electric motor which can be used for propulsion. Electric bicycle motor assists the rider using a pedal-assist system or by a power-on-demand. It can be classified to 3 groups which are electric bicycle with pedal-assist only, electric bicycles with power-on-demand and pedal-assist and lastly electric bicycles with power-on-demand only. The definition of pedal assist is electric motor is regulated by pedaling. It equips with "Pedelec", a sensor that detect the pedaling speed and the pedaling force. Besides, the definition of power-on-demand is the electric motor is activated by a throttle [15].

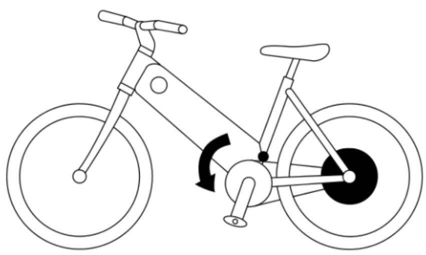

Figure 2.4. Illustration Electric Bicycle with Pedelec [14].

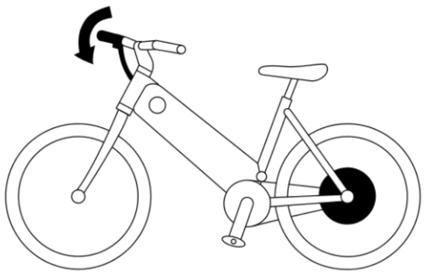

Figure 2.5. Illustration Electric Bicycle with throttle [14].

Furthermore, the e-bike model that been used for this project consist of BLDC motor, set of controllers and 36V battery.

2.5 CYCLE ANALYST V3

The Cycle Analyst V3 measures and displays information about the battery, acts as a general-purpose trip computer, monitors and displays data from optional input devices , records and calculates vehicle and rider performance statistics, and operates or limits the motor controller based on the monitored and calculated data. Combined control for all features is passed to the controller via the throttle signal. The Cycle Analyst can upgrade any motor controller with advanced features like torque-sensing PAS or high temperature power rollback [8].

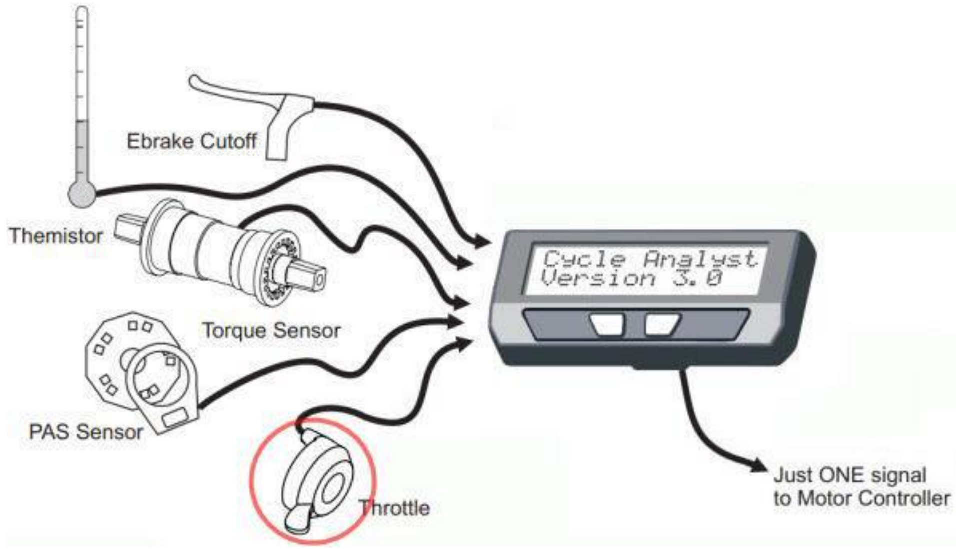

Figure 2.6. Illustration of Cycle Analyst V3[8]

The V3 CA device has a cable bundle bringing out all the signal wires into suitably terminated JST-SM plugs. The following shows the standard CA V3 wiring harness connector details for all cables coming out of the V3 CA:

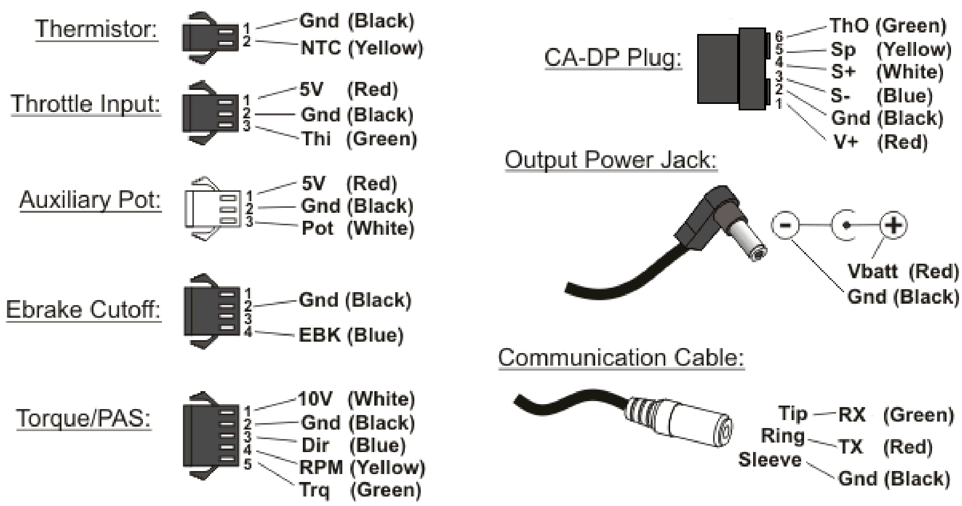

Figure 2.7. Illustration CA V3 connectors [8].

Due to the e-bike controller model and the Cycle Analyst come from different retailer, some modification must be made in order to display the require parameter.

2.6 ANYBODY SOFTWARE

The ANYBODY Modeling System was designed for construct complicated models of the human body and for determine the environment's influence on the body, and it consequently display a computational efficiency that can only be obtained by inverse dynamics [7]. The computational procedure as described in Figure 2.8.

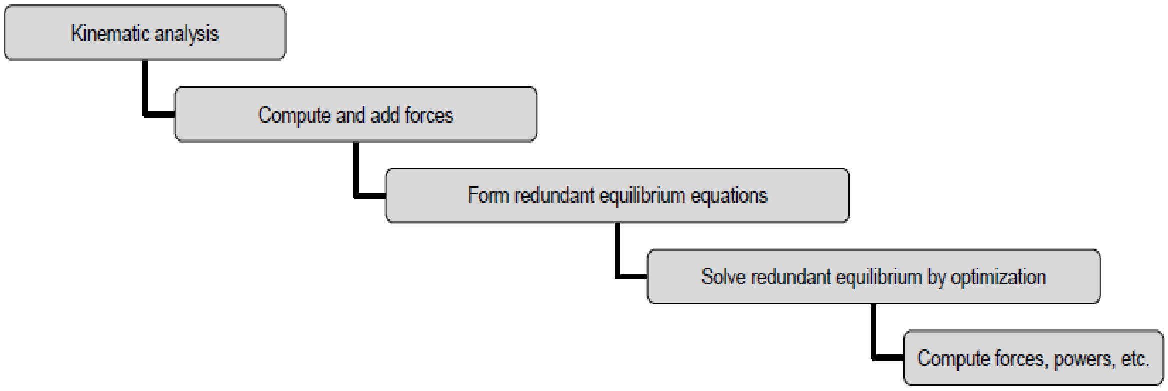

Figure 2.8. The computational procedure for an analysis of the ANYBODY Modelling System [7]

For this project, a model of human riding a bike was used. The parameter of the body model such as body mass and body height can be set. The parameter of the bicycle and the riding characteristic also can be adjusted depends on what we required.

Figure 2.9. Anybody Bike Model.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will be discussing on the flow of the project from the very beginning until the system is complete. There are three stages in completing the project. The first one is to choose the suitable controller and identify all the components needed to integrate with the Cycle Analyst hardware. The second stage is involving the integration the Cycle Analyst with the controller. Finally, is for testing and analysis to verify the objectives of this project. Figure 3.1 shows the general flowchart of the project.

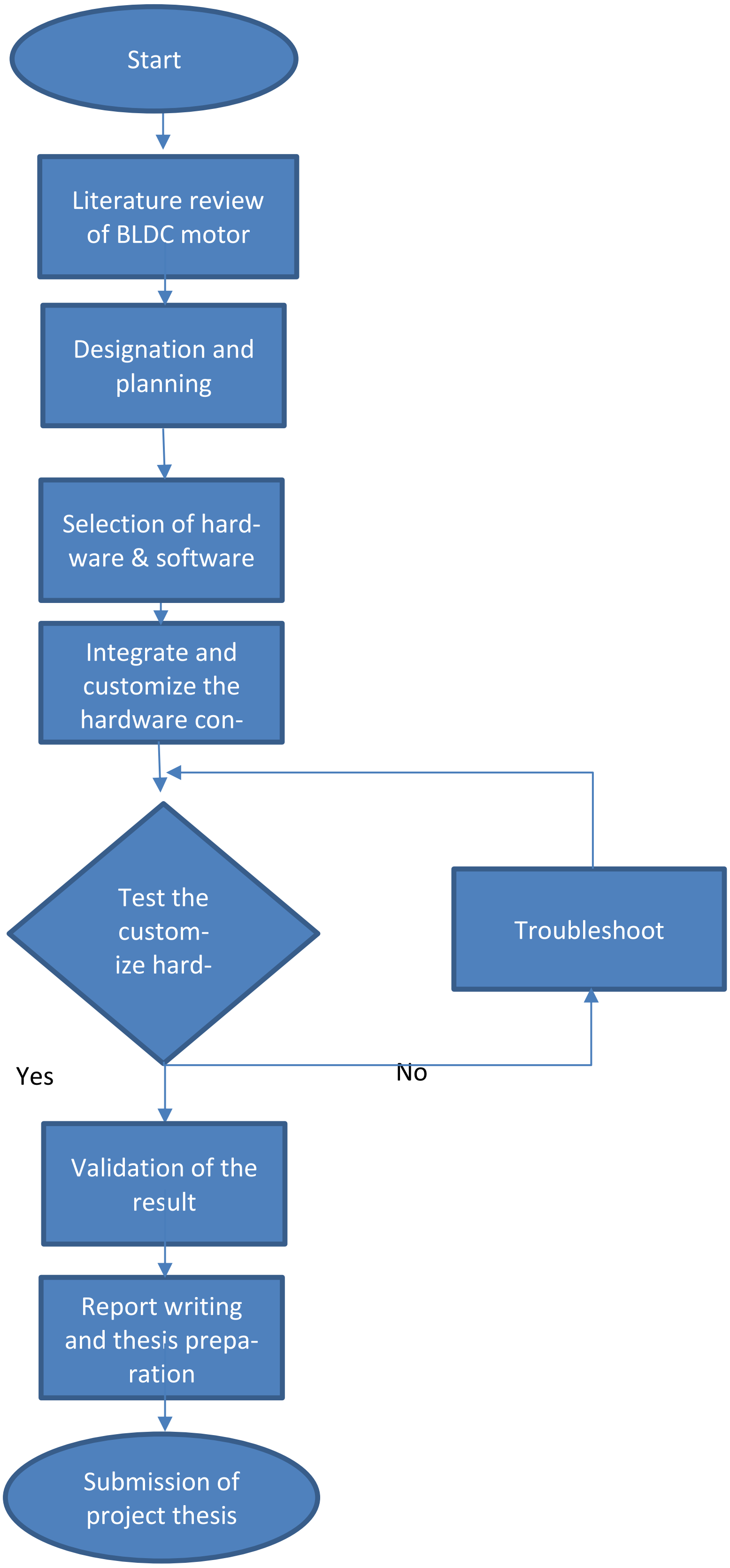

Figure 3.1. Project Flowchart

3.2 SELECTION CONTROLLER FOR E-BIKE

The first thing to do in this stage is to find a suitable controller to be integrate with the Cycle Analyst. Supervisor suggested 3 controllers set which are 6 Mosfet cotroller, 12 Mosfet controller and Magic Pie 4 controller. After several days studying and comparing the controllers, the 6 Mosfet controller was chosen because it small, light and easy to place on the bicycle.

Figure 3.2. 6 MOSFET Controller

The e-bike details are tabulated as below:

Table 3.1. E-Bike Specification

No	Details	Value
1	Rated value battery	36V
2	Rated battery capacity	10Ah
3	Rated controller voltage	36V
4	Rated controller current	12A
5	Rated voltage BLDC motor	36V
6	Rated power BLDC motor	250 Watt

3.3 INTEGRATION CYCLE ANALYST WITH CONTROLLER

Hardware used for this project is Cycle Analyst Version 3. The existing controller does not have CA connector, hence custom wiring must be made so that it compatible with Cycle Analyst. Figure 3.3.1 show CA connector from hardware Cycle Analyst Version 3. There are 6 wire must be connected to the controller. Six locations was needed to be find on the circuit board. Each one will be fed outside the controller and soldered to its own wire. The six locations which corelate to the six pins in the Cycle Analyst connector are:

1. Battery negative
2. Battery positive
3. Shunt negative
4. Shunt positive
5. Signal of hall sensor
6. Signal of hrottle wire

The battery positive and negative wire connected to source either from controller or straight from battery as it used to power up the Cycle Analyst and monitored the battery capacity. Next, the shunt positive and negative wire must be connected to current shunt resistor on the board. Current shunt resistors dan be define as low resistance precision resistors used to measure DC or AC electrical currents by the voltage drop those currents create across the resistance. Furthermore, The Cycle Analyst has to connect into one of the hall sensor wires in order to measure the speed of the motor.Hence it can calculate the speed of the e-bike. Lastly, the throttle signal wire where the Cycle Analyst can monitor how much throttle was twisted.

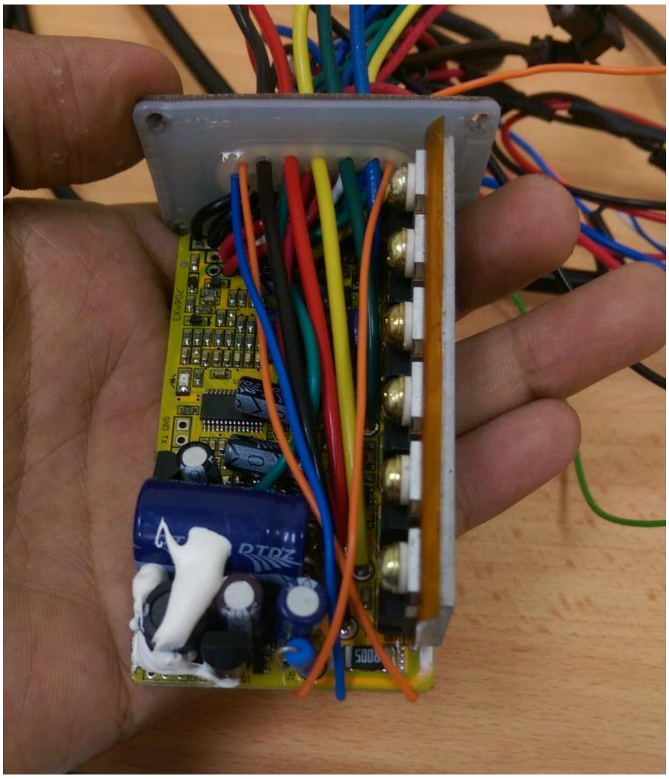

Figure 3.3. Customize controller in process

3.4 TESTING THE CUSTOMIZED HARDWARE

The final stage is to test the hardware so that the objectives of this system can be verified. After the Cycle Analyst and the controller successfully integrated, all cable of the e-bike is connected to run some tests. The power of the Cycle Analyst connected direct to the battery, hence once the battery is on, the Cycle Analyst also on as in figure 3.4.1. Next, the throttle was twisted and make sure the motor run normally or not. The throttle level, voltage, current, power and speed displayed on Cycle Analyst.

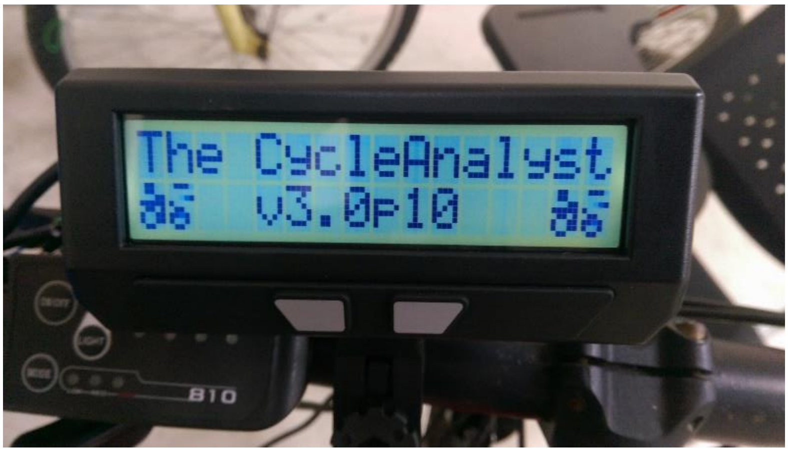

Figure 3.4. Cycle Analyst Display once battery ON

3.5 ANYBODY SIMULATION

For this project, a model of human riding a bike was used. The parameter of the body model such as body mass and body height can be set. The parameter of the bicycle and the riding characteristic also can be adjusted depends on what we required. The body height and mass for the rider was set to average Asian while parameter of the bicycle in simulation is set same as the parameter e-bike used.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, various instantaneous drive parameter of the e-bike was monitored on the Cycle Analyst are the current, voltage, input power, and speed.

4.2 RESULT AND DISCUSSION

4.2.1 Hardware Result

As the Cycle Analyst was turn on, the primary display shows battery fuel gauge, battery voltage, speed, throttle position indicator, distance travelled and battery power draw. Figure 4.1 show the primary display of Cycle Analyst. Next, by push the left button once, it shows the electrical parameter. The second display is the electrical parameter that fed to the motor from the controller. Its shows voltage, power, current, and battery capacity. Figure 4.2 show the electrical stats from second display.

Figure 4.1. Primary display CA V3

Figure 4.2. Electrical parameter display

The result from different throttle level were taken 4 times. The speed limiter at the controller was disconnected to gain maximum power. The minimum value, maximum value and the average of the 4 readings were recorded on the table 4.1.

Table 4.1. Result from Cycle Analyst

Throttle	**Voltage(v)**			**Current(a)**			**Power(w)**			**Speed(km/h)**		
	min	**max**	**ave**	**min**	**max**	**ave**	**min**	**max**	**ave**	**min**	**max**	**ave**
0%	39.1	39.8	39.5	0.00	0.00	0.00	0	0	0	0.00	0.00	0.00
50%	39.1	39.7	39.6	6.35	8.29	7.51	252	324	297	24.9	30.0	27.4
100%	39.3	39.8	39.6	11.03	14.22	13.13	438	559	520	49.5	54.3	52.6

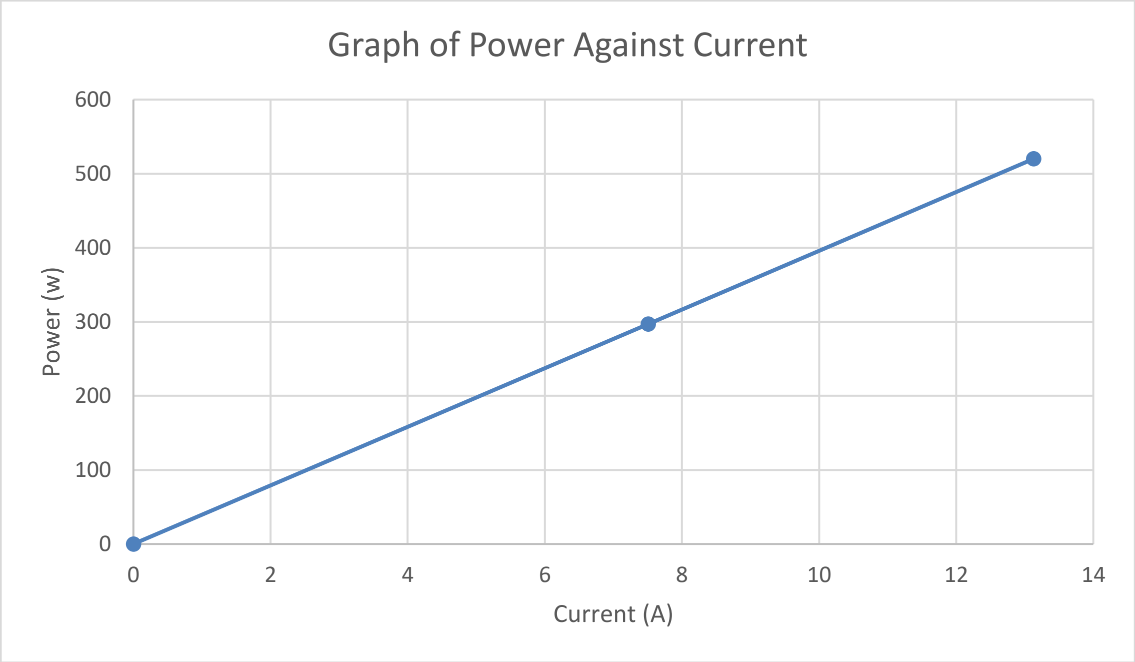

Figure 4.3. Graph Power against Current

From figure 4.3, the graph of power against current, we can conclude that as the current draw to motor increase, the power of the motor also increase. The gradient of the graph represents voltage of the motor where it was constant due to supply from battery.

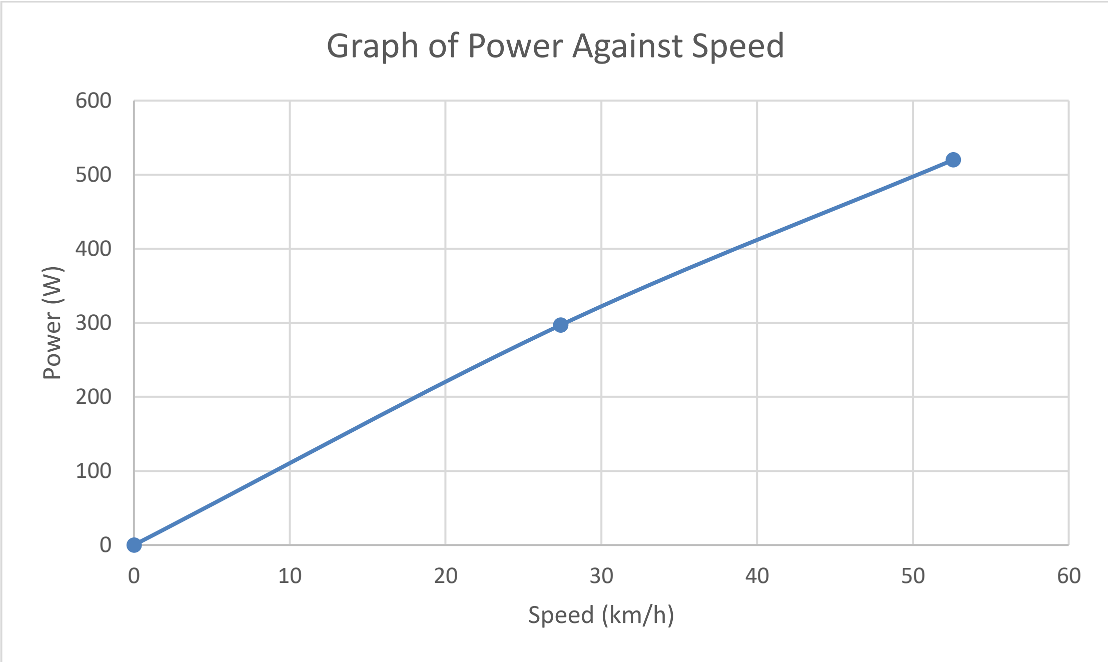

Figure 4.4 Graph of Power against Speed

From figure 4.3 and 4.4, we can conclude that as the current draw to motor increase, the power of the motor also increase, hence the speed of the motor also increase.

4.2.2 Software Result

A simulation from ANYBODY software also had be done to investigate the ergonomic of the e-bike. The software is an applicable system for optimization of ergonomic with respect to the physiological properties of the rider body and the body's interaction with the bicycle. The graph of the muscle activity versus the distance of the bicycle generated as the area under the graph represent total metabolism combust over a crank revolution. For this project, the bike model was used. Figure 4.3 show the bike model from ANYBODY software.

. **Figure 4.5.** Anybody Simulation Bike Model

The rider parameter and the bicycle parameter can bet set from the coding of the software. For this project, the body height and mass for the rider was set to average Asian value which are 171 cm for height and 70 kg for mass. These parameter is important to that the simulation calculate the BMI of the rider. Next, is the bicycle parameter also need to set. The pedal arm length was set to 0.17m, pedal arm width is 0.107m, saddle height is 0.73m and the saddle position is 0.17m. The parameter shown as figure below.

```
// File of anthropometric data
// In this file you have to enter the legnth of each segment individualy

AnyVar BMI = AnthroData.Body_Mass/(AnthroData.body_height^2);
AnyVar FatPercent = (-0.09 + 0.0149*BMI - 0.00009*BMI^2)*100; //Estimation from Frankenfield et al. (2001) valid for men

AnyFolder AnthroData = {
  AnyVar Body_Mass = 75 ;

  //Please note that the height variable is only used for BMI calculation, the segment lenghts determines the height
  AnyVar body_height = (180) /100;


  //Segment masses in kg from Winter ("Biomechanics and motor control of human movement." David A. Winter)
  AnyVar lumbar = 0.139*Body_Mass; // T12-L1 to L5-Sacrum
  AnyVar thorax = 0.1894*Body_Mass; // C7-T1 to T12-L1 (modified from 0.216 winter to separate scapula)
  AnyVar pelvis = 0.142*Body_Mass;
  AnyVar clavicle_r = 0.0133*Body_Mass;
  AnyVar upper_arm_r = 0.028*Body_Mass;
  AnyVar lower_arm_r = 0.016*Body_Mass;
  AnyVar hand_r = 0.006*Body_Mass;
  AnyVar clavicle_l = 0.0133*Body_Mass;
  AnyVar upper_arm_l = 0.028*Body_Mass;
  AnyVar lower_arm_l = 0.016*Body_Mass;
  AnyVar hand_l = 0.006*Body_Mass;
  AnyVar head = 0.081*Body_Mass; // head and cervical
  AnyVar thigh_r = 0.1*Body_Mass;
  AnyVar lower_leg_r = 0.0465*Body_Mass;
  AnyVar foot_r = 0.0145*Body_Mass;
  AnyVar ball_r = 0.000;
  AnyVar thigh_l = 0.1*Body_Mass;
  AnyVar lower_leg_l = 0.0465*Body_Mass;
  AnyVar foot_l = 0.0145*Body_Mass;
  AnyVar ball_l = 0.000;


  // Those two folders are used by the TD leg
  AnyFolder Right ={
    AnyVar thigh = 0.1*.Body_Mass;
    AnyVar lower_leg = 0.0465*.Body_Mass;
    AnyVar talus = 0.0145*0.2*.Body_Mass; //20% of total foot (from bone volume ratio)
    AnyVar foot = 0.0145*0.8*.Body_Mass; //80% of total foot (from bone volume ratio)
    AnyVar ball = 0.000;
  };
  AnyFolder Left={
    AnyVar thigh = 0.1*.Body_Mass;
    AnyVar lower_leg = 0.0465*.Body_Mass;
    AnyVar talus = 0.0145*0.2*.Body_Mass; //20% of total foot (from bone volume ratio)
    AnyVar foot = 0.0145*0.8*.Body_Mass; //80% of total foot (from bone volume ratio)
    AnyVar ball = 0.000;
  };
```

Figure 4.6. The setting parameter of the rider body

```
/// Various parameters for setting up the bicycle and the riding characteristics.
AnyFolder BikeParameters = {

  // Geometry parameters
  AnyVar PedalArmLength =0.17;  //Length of pedal arm
  AnyVar PedalArmWidth = 0.107; //Horizontal distance between left and right connecting point between foot and pedal
  AnyVar SaddleHeight = 0.73 ;  //Height of hip joint measured vertically from the crank
  AnyVar SaddlePos = -0.17;     //Horizontal pos of hipjoint measured from the crank

  // Performance parameters
  AnyVar Cadence = 80.0;   //Cadence in RPM
  AnyVar MechOutput = 170; //Average Mechanical output over a cycle in Watt

  // The function for the crank moment is defined as Moment=Offset-Amp*cos(4*pi*t/T+Phase)
  AnyVar T = 60/Cadence; //Cycle time

  AnyVar CrankMomentTopDeadCenter = 3.0; // Crank moment at the top dead center.
  AnyVar CrankMomentOffset = (MechOutput*T)/(2*pi);
  AnyVar CrankMomentAmp = CrankMomentOffset-CrankMomentTopDeadCenter;
  AnyVar CrankMomentPhase = -15*pi/180;
};

// Attachment position of the bike frame to the global reference frame
AnyFixedRefFrame GlobalRef = {
  AnyRefNode Bike3DGround = { sRel = {0,0.0,0.0}; };
};  // Global reference frame
```

Figure 4.7. The setting parameter of the bicycle

As the simulation run, the result show the graph of the muscle activity versus the distance of the bicycle generated as the area under the graph represent total metabolism combusted over a crank revolution. Metabolism technically a power measured in Watt, and the summation of the individual muscle activation/metabolisms give result of an estimate of the total metabolism involved in the bicycling process. The mechanical output was set differently same as got in the Cycle Analyst.

The graph result show as below:

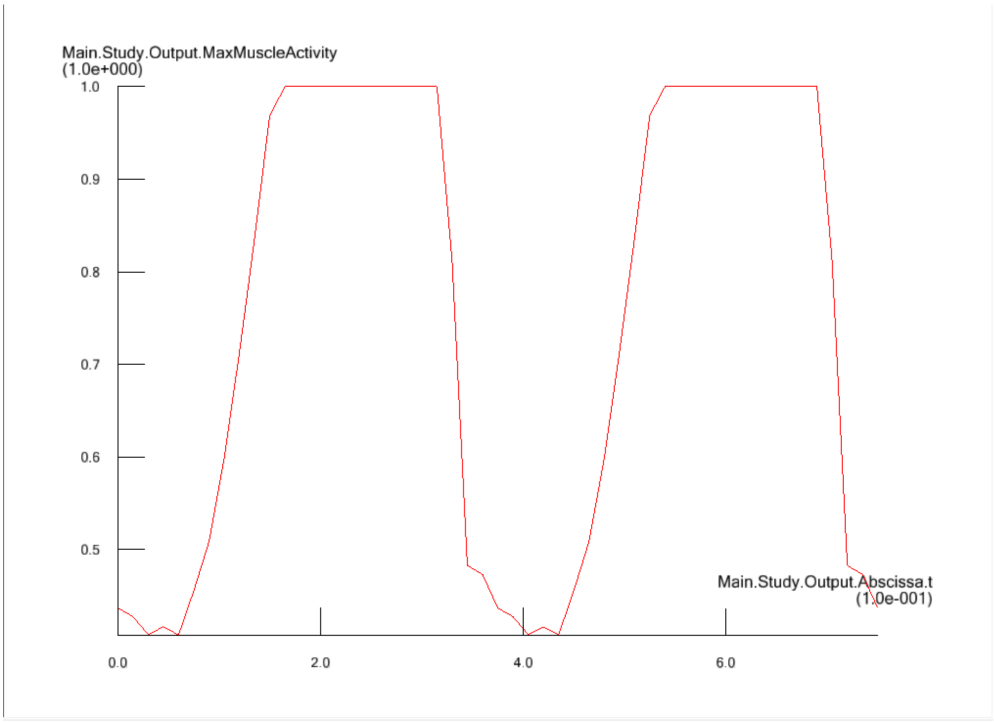

Figure 4.8. Graph for 170 Watts mechanical output

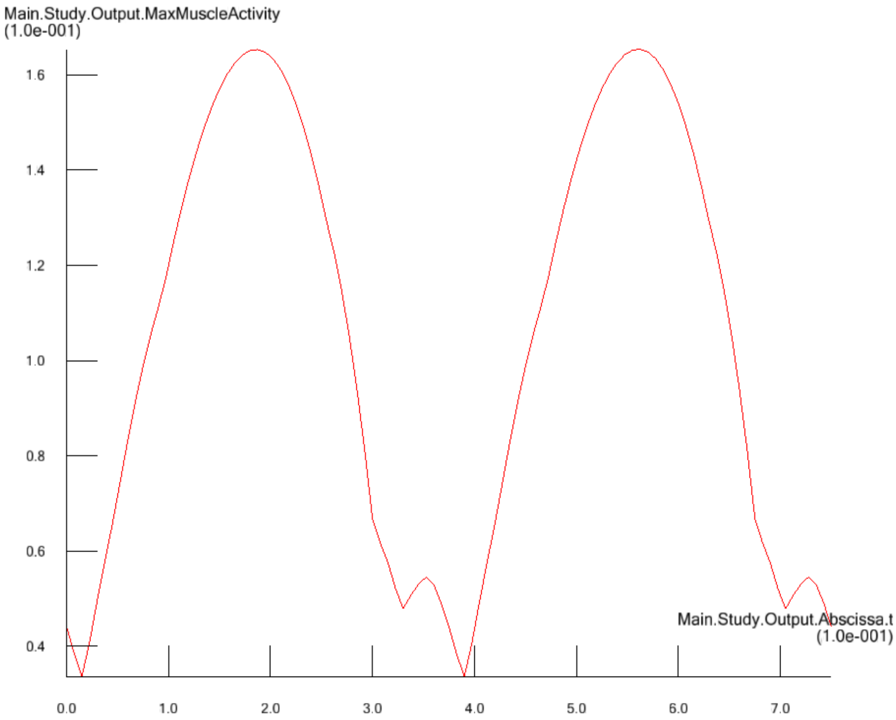

Figure 4.9. Graph for 250 Watts mechanical output

The Y-axis of the graph represent the cumulative of muscle activity while X-axis show the distance travel. Abscissa means the perpendicular distance of a point from the vertical axis. The positive value of abscissa means the bicycle ride forward while if the negative abscissa means the bicycle ride backward. The minimum value of the muscle activity show that the muscle is in relax position and the most ergonomic position for rider. While the maximum value of the muscle activity show that the muscle is in strain position and the not the ergonomic position for rider. As the muscle activity increase, the area under the graph also increase, total metabolism combust over a crank revolution also increase. As we can observe, the higher the mechanical output, the higher the muscle activity and the bicycle ergonomic decrease.

CHAPTER 5

CONCLUSION & FUTURE DEVELOPMENT

5.1 CONCLUSION

At the end of this project, the customize controller integrated well with CA V3 as its can show various instantaneous drive parameter. The technical performance parameter of the electric bicycle drive systems for cycle operation can be evaluated by model implementation that uses riding profile based on actual road tests. The implementation shows the characteristic of a given drive depends on riding profile characteristics. From the simulation, the data used from CA V3 show the muscle activity increase as the power use by the rider increase. Hence, the bicycle ergonomic decrease for the rider because total metabolism combusted over a crank revolution also increase.

5.2 FUTURE DEVELOPMENT

For future development, the recommendation for the improvement of the circuit must be made. With more studies and customization on the controller set and CA V3, other parameter such as temperature, battery State of Charge(SOC) estimator and Low Voltage Cutoff (LVC), PAS Sensor and Torque sensor can be made. The hardware can be used to develop more answers toareas of drives of BLDC motor operation with respect to the different torque-speed combination and the derivation with respect to time which occur to electric bicycles. Hence, the performance and efficiency of EV can be increased and replaced fuel powered vehicle for better future.

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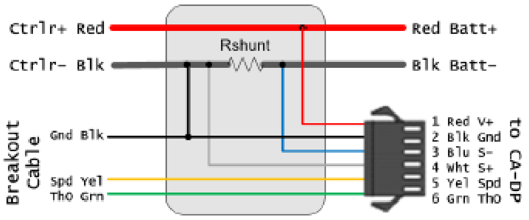
APPENDIX A

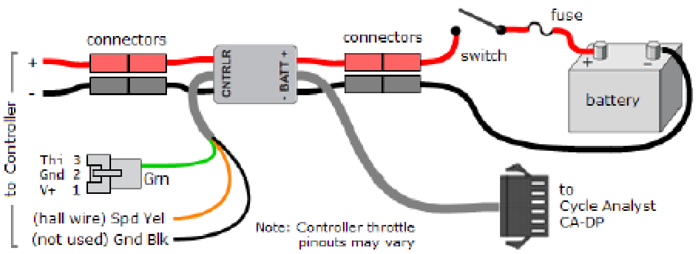
4.2.1.4 Installation with Cycle Analyst Molded External Shunt Module (Normal Mode)

The Grin Tech CA Molded External Shunt uses a 1.0mOhm shunt resistor and brings out necessary CA shunt and power connections to a 6 pin CA-DP compatible connector. The unused CA-DP **Spd** and **ThO** signals are brought out to a Breakout Cable for custom handling. The rated capacity is 50A but sanding the face flat and clamping the shunt to an aluminum plate or other heatsink will allow higher current.

The module 'Controller' and 'Battery' wires are unterminated and can be permanently wired in place or fitted with connectors.



CA Molded External Shunt



Connect the shunt as shown to the left.

The green **ThO** wire from the breakout cable provides the controller throttle Sense signal. Attach an appropriate mating connector.

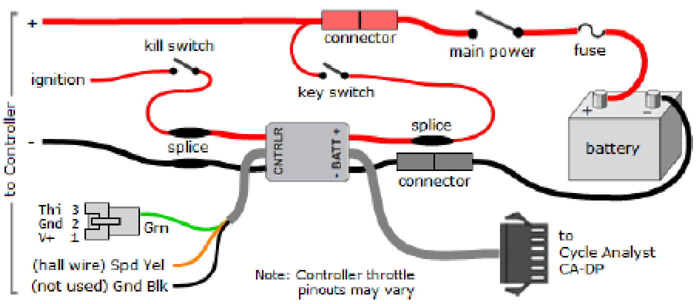
The yellow **Spd** wire from the breakout cable can optionally be tied to any motor hall wire (between hall connector and controller) as an alternative to using a wheel pickup.

As shown in the top illustration, the shunt resistor is in the negative power path and carries primary controller power. However, the heavy red positive leads are only a packaging consideration and a convenient means to pick up **Vbatt+** for CA power and monitoring; *they need not carry primary controller power*.

For instance, if a key switch is desired, then **Vbatt+** can bypass the shunt module and run directly to the controller. The controller 'ignition' lead carries **Vbatt+** back to the controller to power the +5V regulator and logic by way of the key and kill switches. Normally, when a controller has a CA interface connector, the ignition **Vbatt+** runs to pin 1. In this case with no controller CA interface connector, **Vbatt+** is picked off the key switch and is run to either of the shunt module heavy gauge red power leads to supply pin 1 of the shunt module CA connector. The other heavy red module lead need not be connected or can be used as a pass-though as shown below.

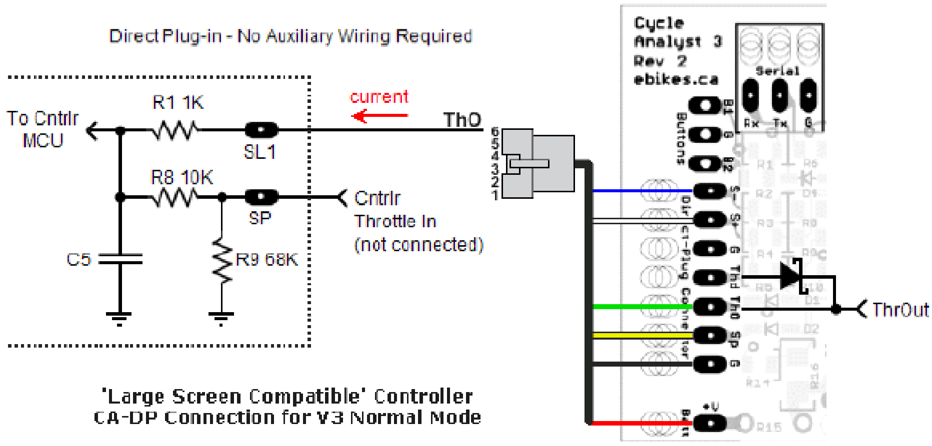
Note: A CA Adapter Module may be stacked with the molded External Shunt Module to provide throttle and ebrake signals to the controller (e.g. for regen braking). In that case, the Adapter Module throttle connector must be used in lieu of the green breakout cable wire (see *' 5.4 Ebrakes'*).

Step Complete. Go to section *' 4.2.2 Mount Console and Wheel Pickup'*.



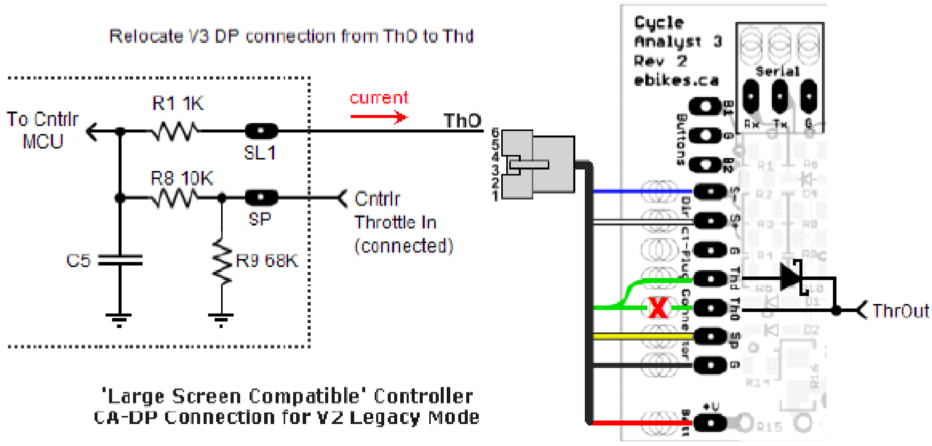
This newer style controller interface has been available since mid-2013. The first illustration outlines the preferred 'normal' mode of operation. Note that the solder pad labels are specific to the Grinfineon and may differ from those of other Infineon (Xie Chang) controllers.

Direct Plug-in - No Auxiliary Wiring Required



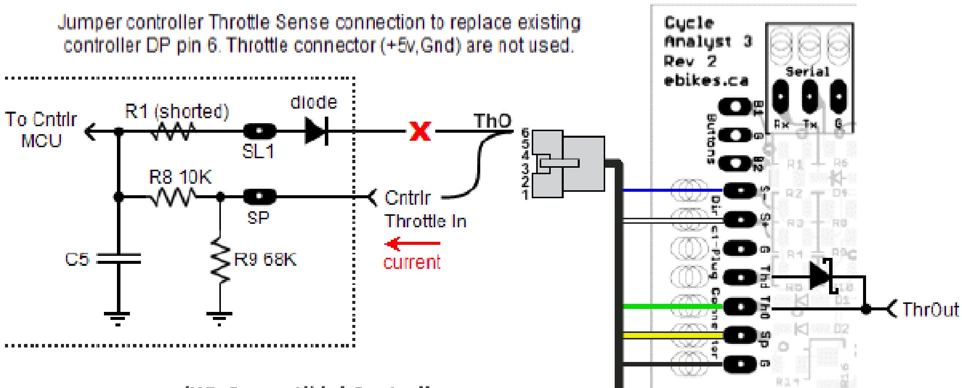
'Large Screen Compatible' Controller
CA-DP Connection for V3 Normal Mode

Relocate V3 DP connection from ThO to Thd

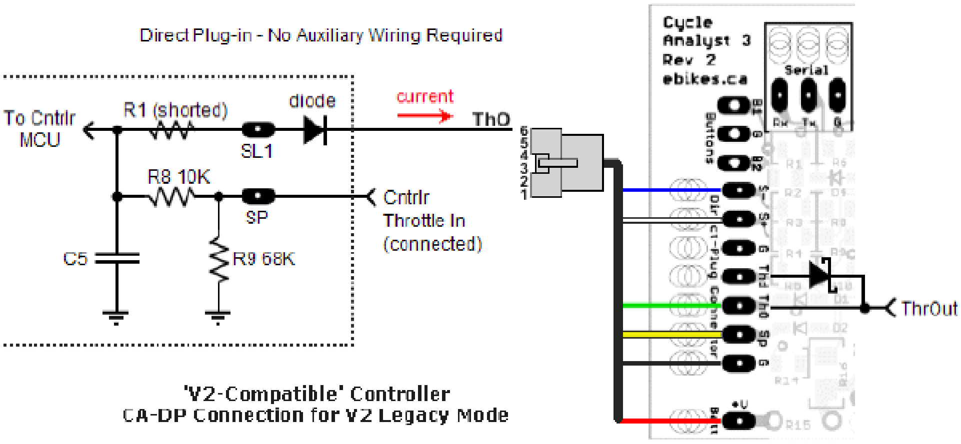


'Large Screen Compatible' Controller
CA-DP Connection for V2 Legacy Mode

If wired as shown below, controllers with this older interface design will provide the same functionality as those with the newer interface. The first illustration outlines the preferred 'normal' mode of operation.



'V2-Compatible' Controller
CA-DP Connection for V3 Normal Mode

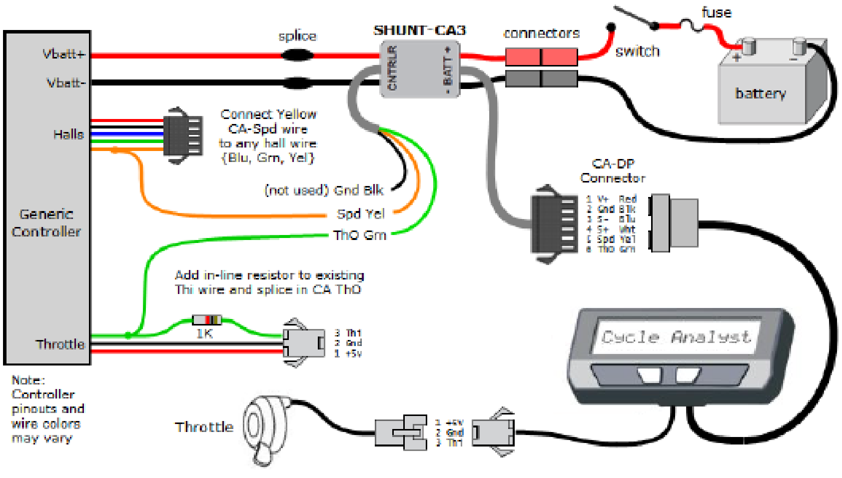


'V2-Compatible' Controller
CA-DP Connection for V2 Legacy Mode

A CA-DP connector may be added to a generic controller by opening the controller, adding connections to access power and the internal controller shunt, and making minor wiring modifications to implement throttle override. That strategy can yield a very finished looking conversion but requires more time, skill, and risk than necessary. Identical functionality can be obtained using only basic wiring skills and without opening the controller.

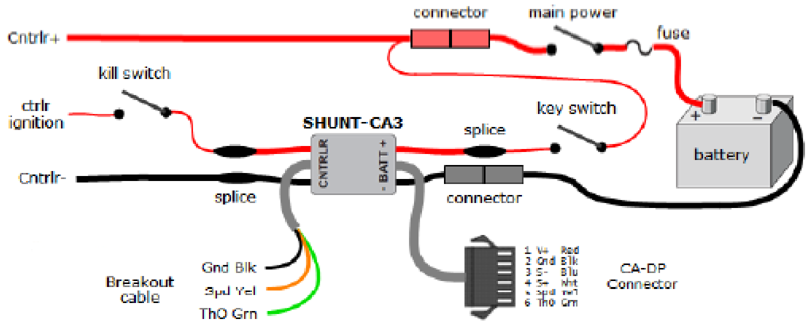
The illustration below is a combination of a standard external shunt installation and a 'normal mode' throttle hook-up as described in earlier sections. This combination effectively adds a 'Large Screen Compatible' CA connector (the shunt connector) to a generic controller. The new connector is plug and play with either a CA V3 (throttle plugged into the CA) or 'Large Screen' V2 with PCB rev 11 or greater (throttle plugged into the controller).

Current monitoring and throttle override are provided by a stock external (SHUNT-CA3) from Grin Tech and a 1K resistor. (Note that although the resistor power requirement is tiny, choosing a higher wattage part (1/4W – 1/2W) will give more robust leads for in-line connection – a purely mechanical consideration.) As always, if the CA is a DPS type using a wheel sensor, the yellow Spd connection to the hall may be omitted and the wire re-purposed for a temp sensor, etc.



Adding Large Screen V2/V3 CA-DP Connector to Generic Controller Using SHUNT-CA3

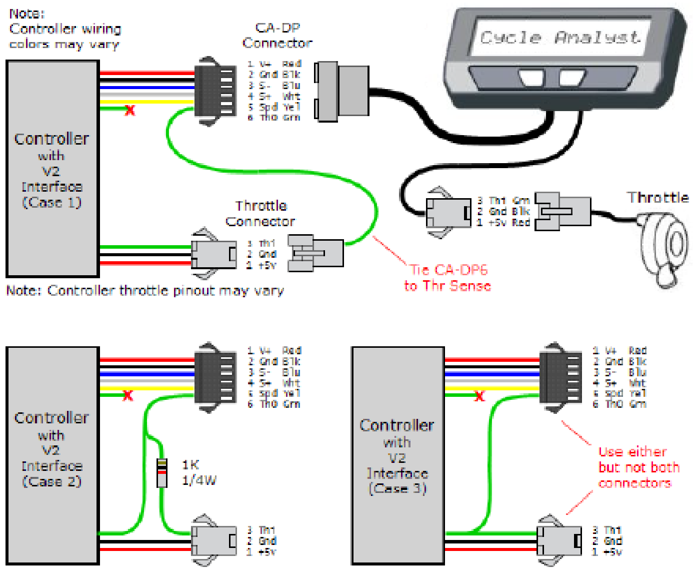
If the controller has an 'ignition' wire, the power portion of the circuit above might be modified as shown below to add key and kill switches. Note the use of light gauge wire for the added switch connections.



Alternate Power Configuration for Key and Kill Switches

The CA-DP cable is plugged into the mating controller connector, but the CA-DP connector pin 6 throttle signal must be severed and re-routed to the controller throttle input connector. There are many means to accomplish this - five examples are shown below. Select and implement one option (Cases 1, 2, or 5 are recommended):

1. Modify the controller wiring to bypass the V2 style interface and provide a 'V3 Compatible' interface instead. The illustration below shows three means to achieve this.
   a. **Case 1:** Pin 6 of the controller CA connector is re-routed to the 'Sense' pin of a mating throttle connector and plugged into the controller. The controller can be restored to normal operation by instead plugging in an operator throttle.
   b. **Case 2:** Pin 6 of the controller CA connector is routed directly to the controller throttle 'Sense' input wire and a 1K resistor is added as shown. This converts the controller to the newer 'Large Screen Compatible' interface so it will work with either V2 or V3 Cycle Analysts.
   c. **Case 3:** This is a simplified version of Case 1 without the connector. The throttle and CA interface connectors must not be plugged in at the same time – use one or the other – not both.



For Case 2: Sleeve the resistor together with the adjacent wire for strength

2. Or Modify the CA-DP cable by removing the heatshrink from the CA-DP connector, sliding out pin 6, then seating pin 6 into a mating connector for the controller throttle input (**Case 4**).