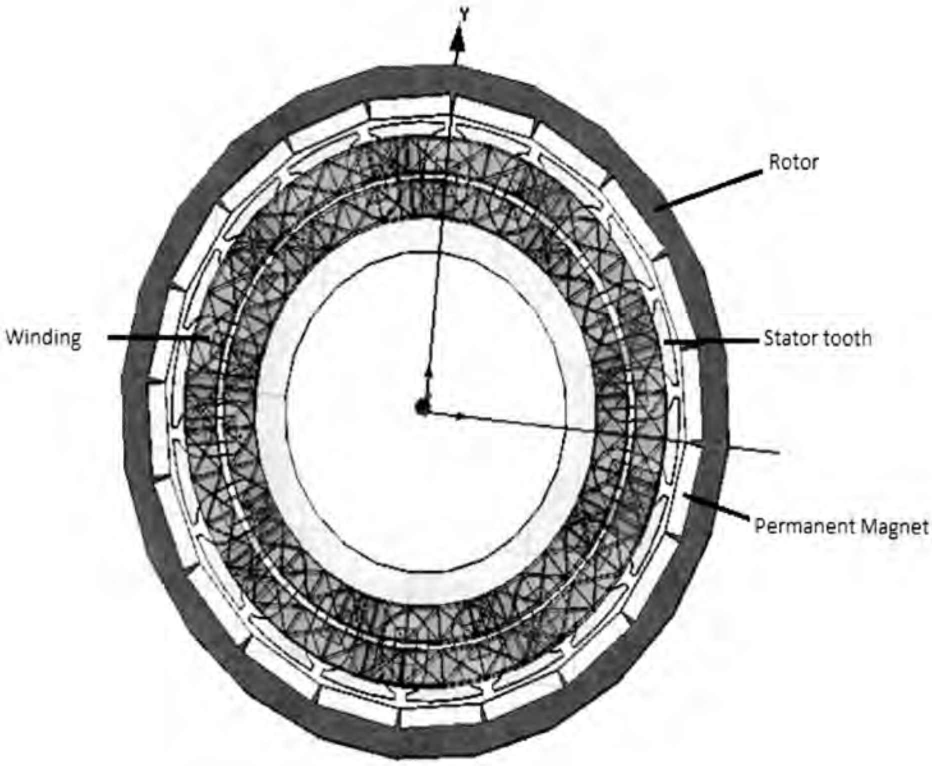

DEVELOP A DIRECT DRIVE SYSTEM FOR ELECTRIC MOTORCYCLE

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1. Introduction

This application based research was initiated to design an electric motorcycle using direct drive technology. This research was to invent a small application of electric motor to drive a motorcycle. The main objective of this research is to eliminate the conventional method in electric motorcycle whereby a conventional internal combustion engine is replaced by an electric motor.

2. Background

This project deals with analytical design of a permanent magnet synchronous brushless DC motor for electric vehicle (EV) application. Unlike conventional drive system, torque as well as the power and speed can be directly supplied to the wheel using a Hub motor. This arrangement eliminates the gear, chain and need for mechanical differentials. Brushless DC permanent magnet motor is simple in construction and robust. The recent advances in power electronics technology have made Brushless DC permanent magnet motor suited for many of the emerging applications for electric drive system.

This project aims at design, construction and testing of a 1000 W, 36 V and 15 N-m Brushless DC permanent magnet hub motor. The design of a Brushless DC permanent magnet hub motor need to comply with diameter restrictions due to the housing of the motor in wheel's center hub as shown in figure 1 below. This arrangement can achieve the level of efficiency, compactness and low manufacturing cost. Hence the peripheral length of the machine is restricted to 320 mm with outer diameter is 100mm and the axial length is 40mm.

Fig. 2: (In red circle) Wheel´s spoke is use to house the brushless DC permanent magnet synchronous motor.

Since Neodymium-Iron –Boron (NdFeB) permanent magnet (PM) materials were introduced and invented in 1980's, PM machine are widely used in large-scale industrial applications. This type of machine are a better choice or at least as an alternative to a conventional motor[1] such as in –wheel motor for electric vehicles (EV), wheelchair motors, generators dedicated to wind and ocean energy applications.

The concept of in-wheel motors for EVs appeared in the 1990's. Today many private companies are working on in-wheel motors and most of race-winning solar car uses this technology. Having a direct drive electric motor inside wheel eliminates many of the conventional modules in the motorcycle such as gearbox, chain and the IC engine.

3. Research Methodology

The concept design approach as shown in figure 2 consists of a 36V battery, a three phase inverter which converts the DC source to AC, a controller to control the speed and torque of the in-wheel Brushless PM synchronous motor and an in-wheel Brushless PM motor. The in-wheel Brushless PM motor has a crucial constraint on volume envelope and on the drive since the peripheral length of the machine is restricted to 320 mm with outer diameter is 100mm and the axial length is 40mm.

The considered motor drive is the three-phase DC/AC converter, which is commercially available on the modern market of the standard variable frequency drives. The design of a 1kW in-wheel hub motor will be of a surface-mounted PM (SPM) motor with distributed armature winding. The design of the motor includes electromagnetic, losses and thermal analyses to define the motor performances and thermal conditions.

A design procedure will be evolved from the basic background in electromagnetic. Subsequently a finite element magnetic software or equivalent will be used for verifying power, winding inductance and torque. When it is necessary, design will be modified until it converged to a set of consistent dimensions for both mechanic and electromagnetic design

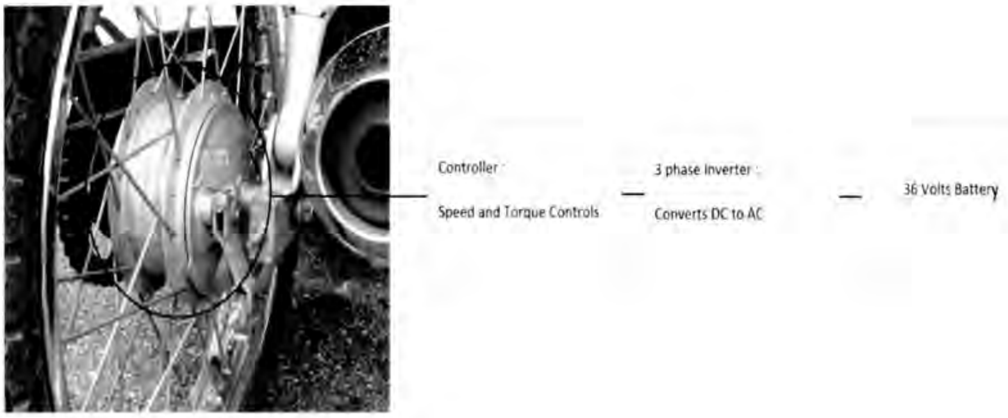


Figure 3.1: Direct drive system for electric motorcycle application.

4.0 Motorcycle Selection

The desired motorcycle chassis had to meet the following specifications:

- Large Engine to provide ample space for batteries and electric motor
- Steel frame for ease of modification
- Lowest possible weight
- Rear sprocket
- Operation brakes
- Good tires and suspension
- No damage to the frame
- Low cost

The motorcycle chassis chosen was a Yamaha 110. The large engine compartment created an ideal amount of space for four 12 volt batteries. Unfortunately the motorcycle had a very heavy frame compared to some of the other motorcycles that were considered. Another deciding factor was the steel frame.

Table 4.0 Motorcycle specification

Length		Total Weight	
Width		Engine Dry Weight	
Height		Frame Weight	
Seat Height		Maximum RPM	
Wheel base		Power	
Minimum ground Clearance		Torque	

4.1 Motor

The electric motor is designed based on the motorcycle's specification. The main consideration for the motor design was the torque value, whereby sufficient torque is needed to be able to drive the motorcycle.

Design flow of an electrical machine is shown in Fig. 4.1

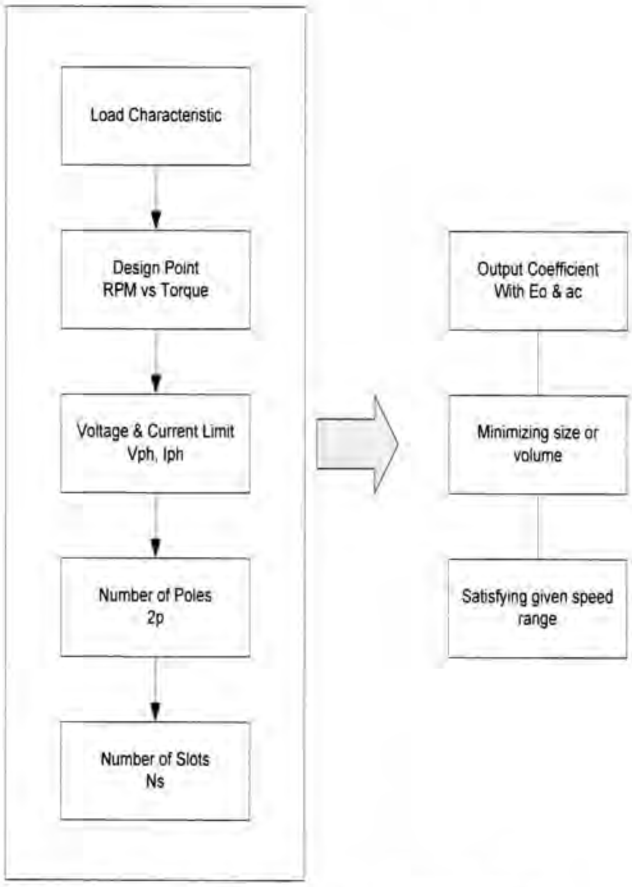


Fig. 4.1. Electric machine design flow.

Finite element software is used to design the motor as shown in fig. 4.2

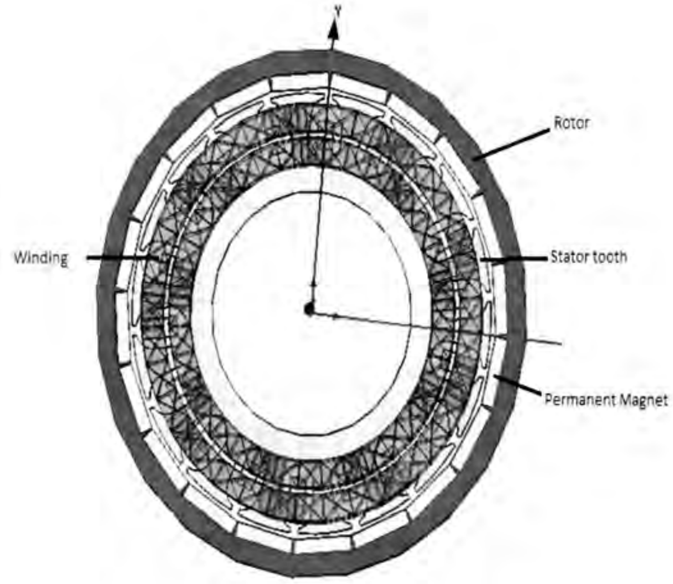


Fig. 4.2: Finite element software to calculate desired value for electric motor in 3D

Due to low computer specification, simulation in 3D was unable to generate, therefore 2D model is used as in Fig.4.3.

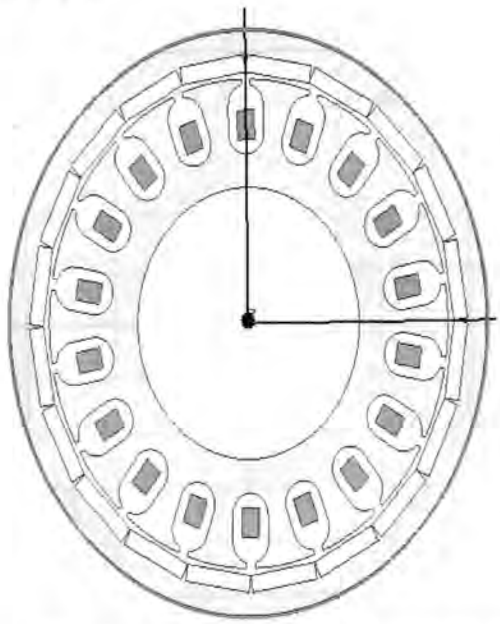


Fig. 4.3: Finite element software to calculate desired value for electric motor in 2D

4.2. Batteries and Charger

The desired specifications for the battery were as follows:

- Deep cycle batteries
- 4 x12 volts for 48 total volts
- High amp hours
- Light weight
- Compact size
- Reasonably priced

Four MS17-12 batteries, manufactured by MSB. Batteries, were selected for the power source. The batteries are 12 V batteries and weigh in at 5kg each. The MS17-12 has an amp hour (Ah) rating of 17 Ah. The MS17-12 battery is lighter and smaller than a typical 12 V car battery that was originally considered.

The battery charger purchased for the project was a 48 V, 4 amp charger. This charging system will charge fully discharged batteries in eleven hours.

5. Results

5.1 Simulation

Based on the simulation results, the electrical motor has sufficient power to drive the motor frame with load. The load here is defined as rider, passenger and battery. Motor design was constructed as in section 4. By using finite element software, important parameters are determined. Figure 5.1 to 5.4 show speed, current, power and efficiency against torque value respectively.

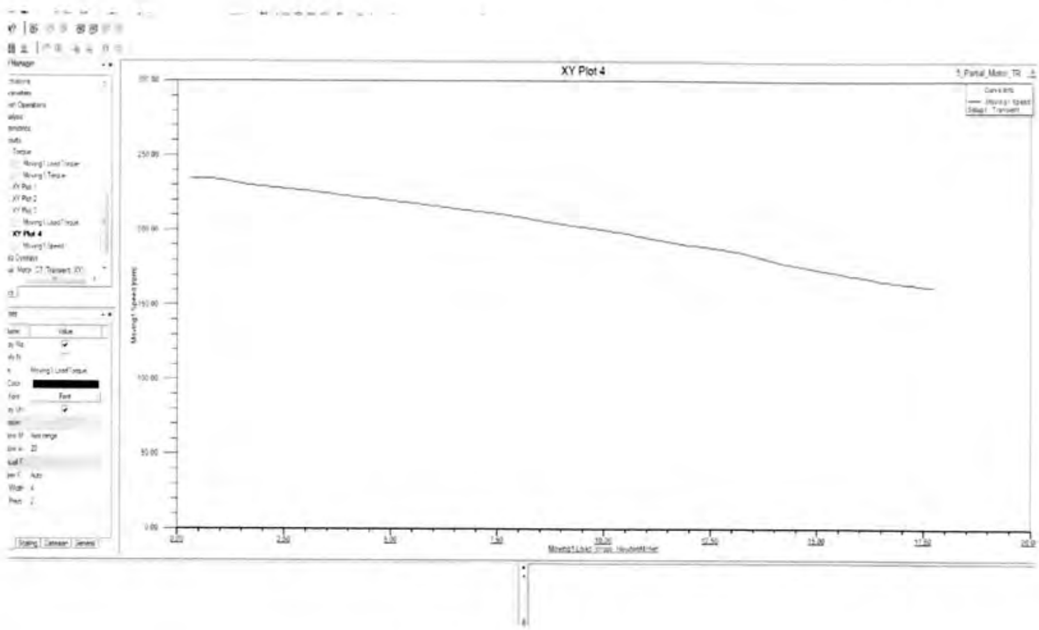


Fig. 5.1.1: speed vs torque

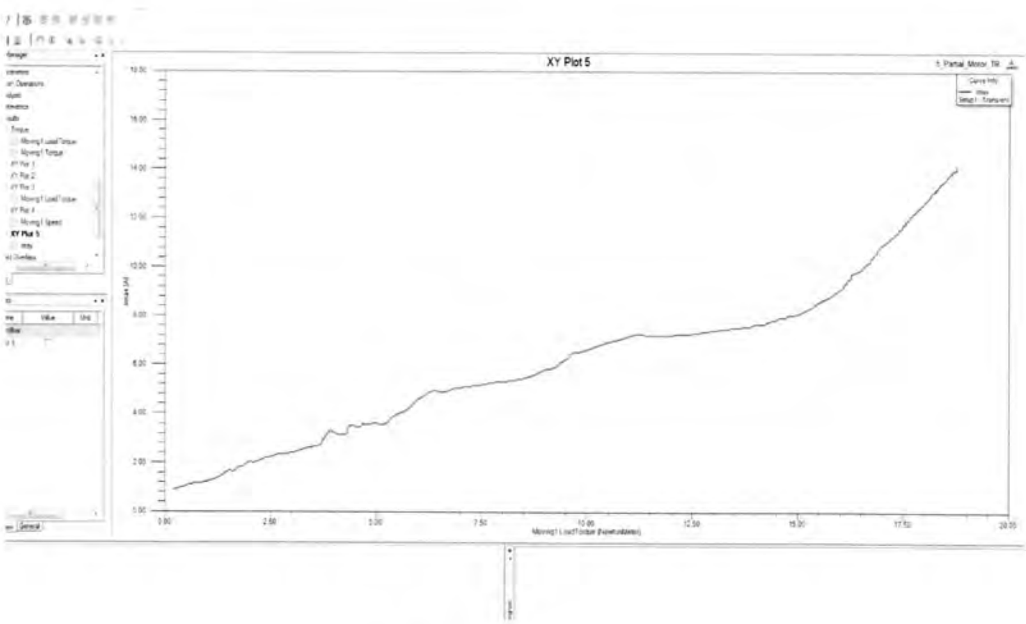


Fig. 5.1.2: current vs torque

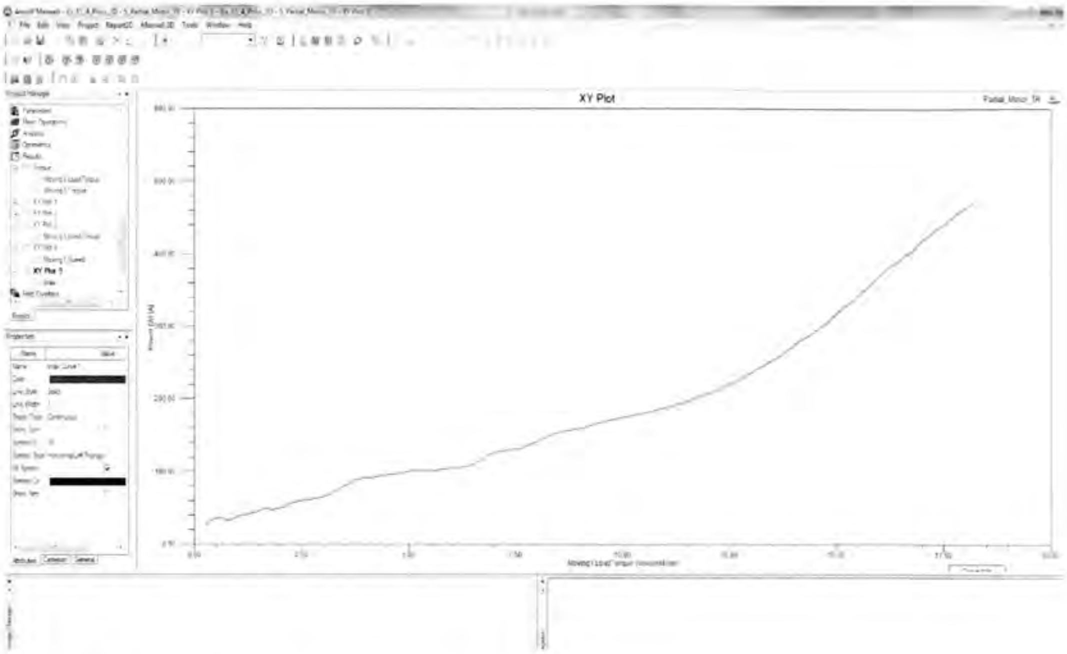


Fig.5.1.3: Mechanical power vs torque

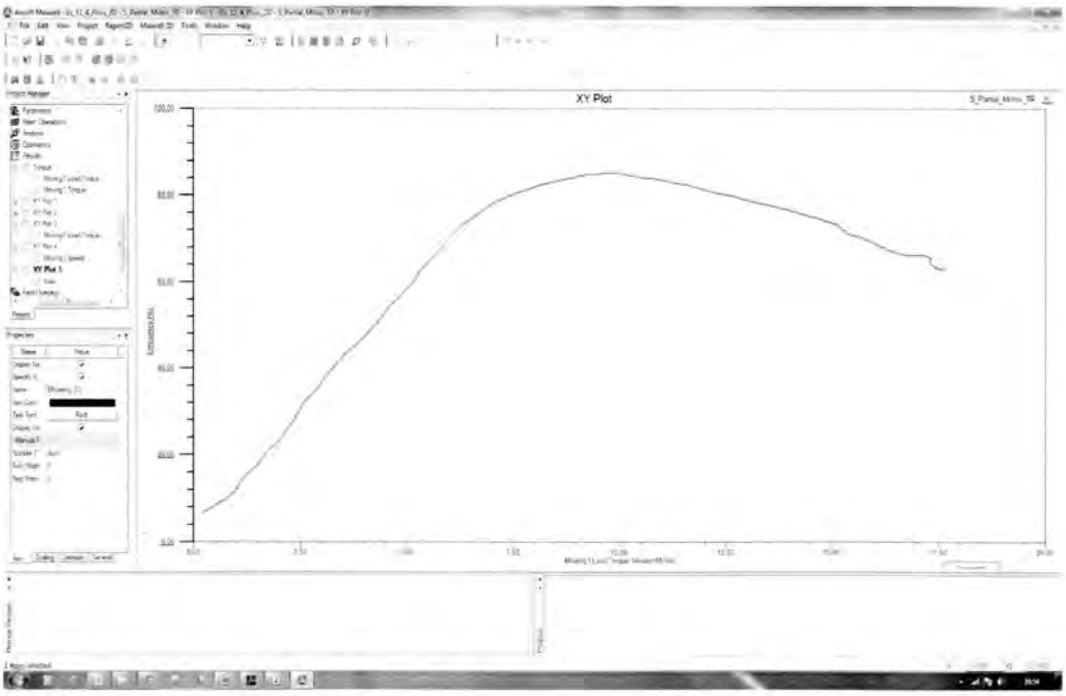


Fig.5.1.4: Efficiency vs torque.

Based on the graphs as shown in fig 5.1-5.4, it can be seen that, at rated torque the current is 8A, output power is 320 W (way below from the expected value which is about 1kW), speed is 170 rpm and efficiency is 75% respectively. The motor operates at the highest efficiency i.e 86% at torque of 10Nm.

5.2 Experiment

The machine is constructed as shown in figure 5.2.1 while figure 5.2.2 is the controller of the machine manufactured by Magic Motor.

The motor controller has special capabilities such as:

- Cruise Speed Control
- Motor hall sensor failure redundency (Automatically switch to sensorless control)
- Anti-theft alarm and wheel-locking by detection of vibration
- Other failures redundency (Work with failed throttle and power breaker)
- You can force it to work with higher voltages (e.g 24V controller can drive 36V and 48V motors)
- Report failure components by beeps
- Motor phase self detection and calibration
- Support Forward and Reverse Control
- Excessive Current Protection
- Low Voltage Protection

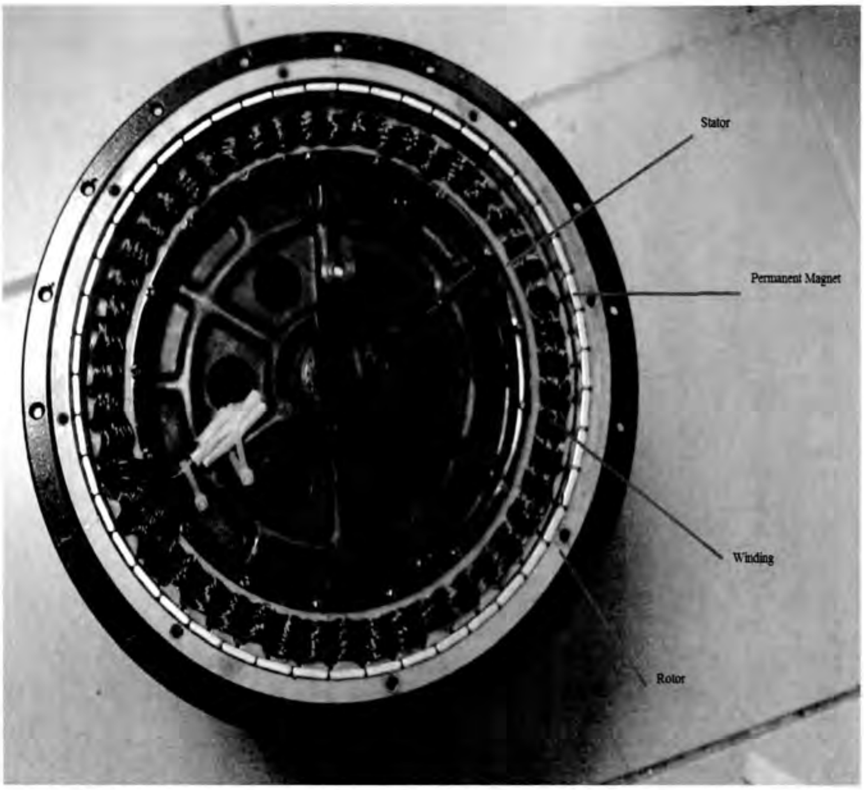


Fig. 5.2.1: 1 kW 48V Hub wheel motor

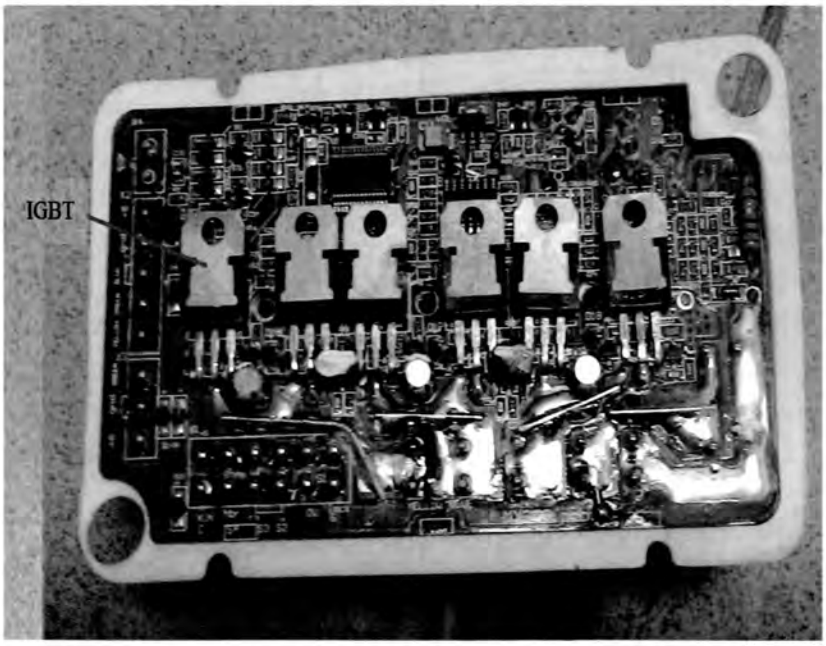


Fig.5.2.2: Motor controller with IGBT, capacity upto 5kW, type BAC-0282 48V/30A manufactured by magic motor.

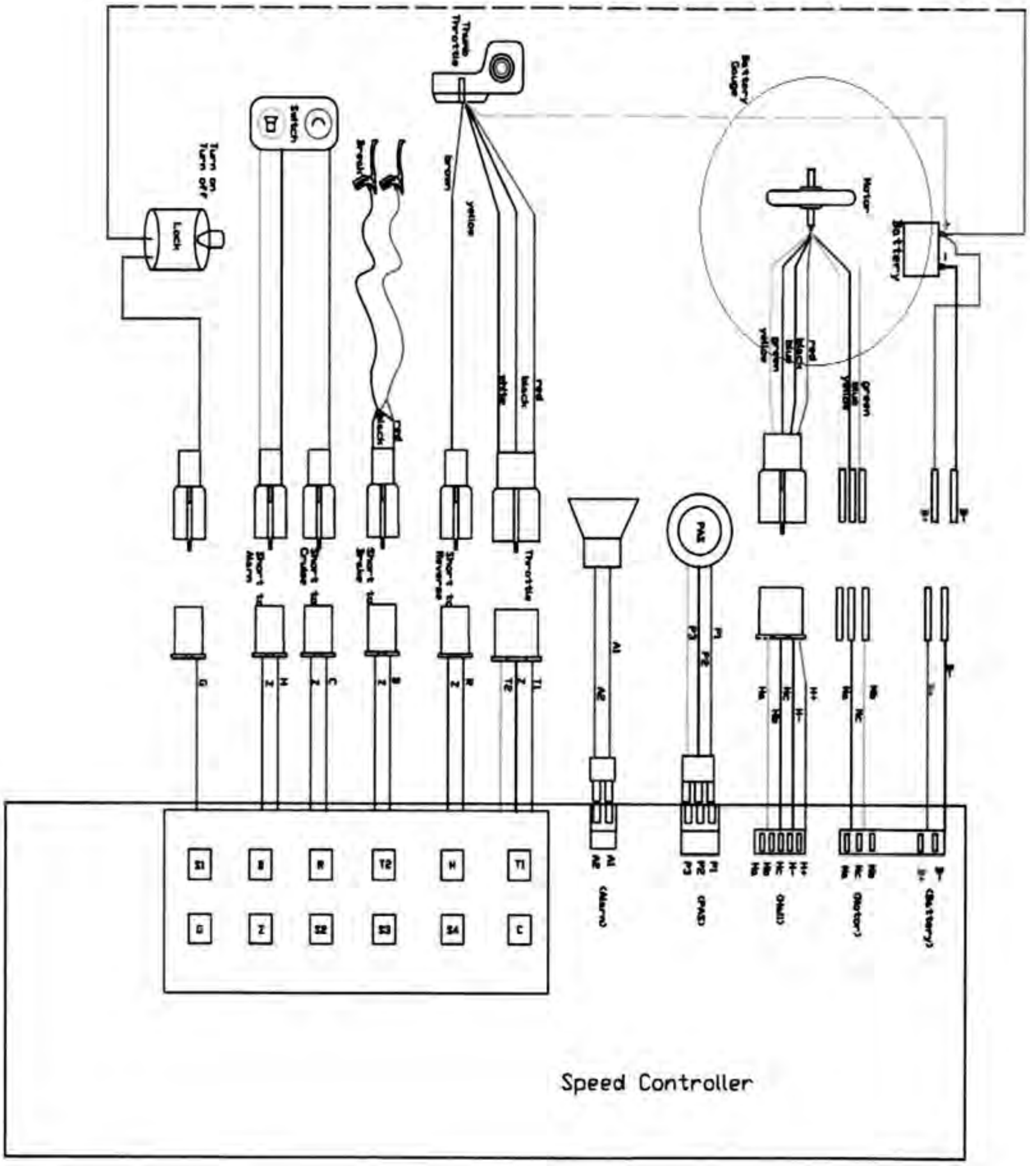


Fig.5.2.3: Wiring diagram for direct drive electric motorcycle system

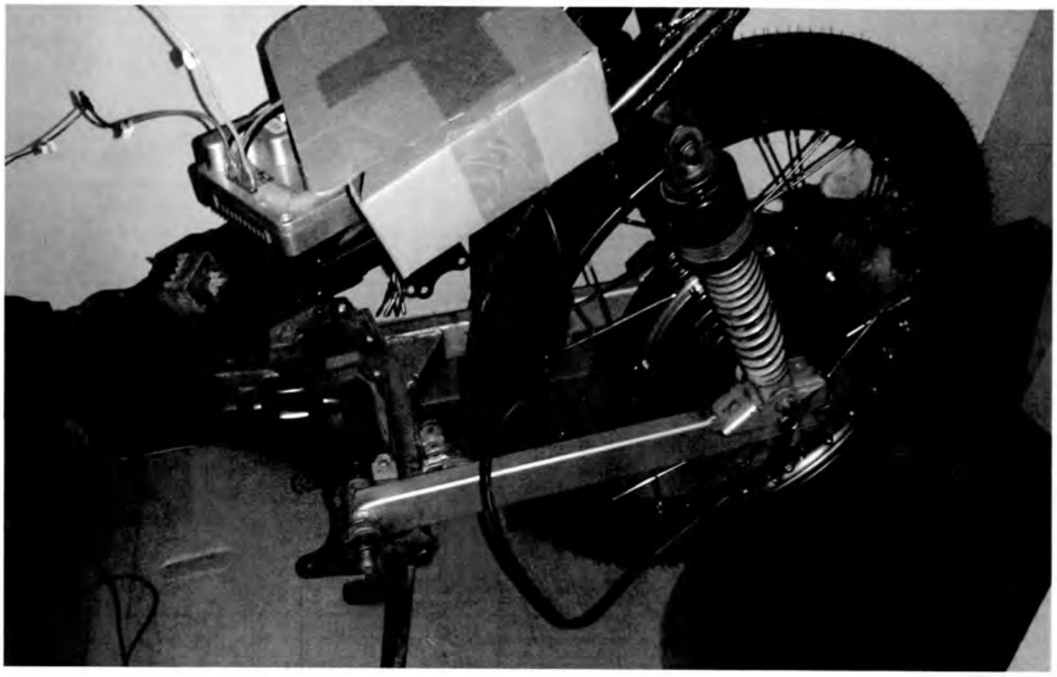


Fig.5.2.4: Assembly of Hub wheel motor

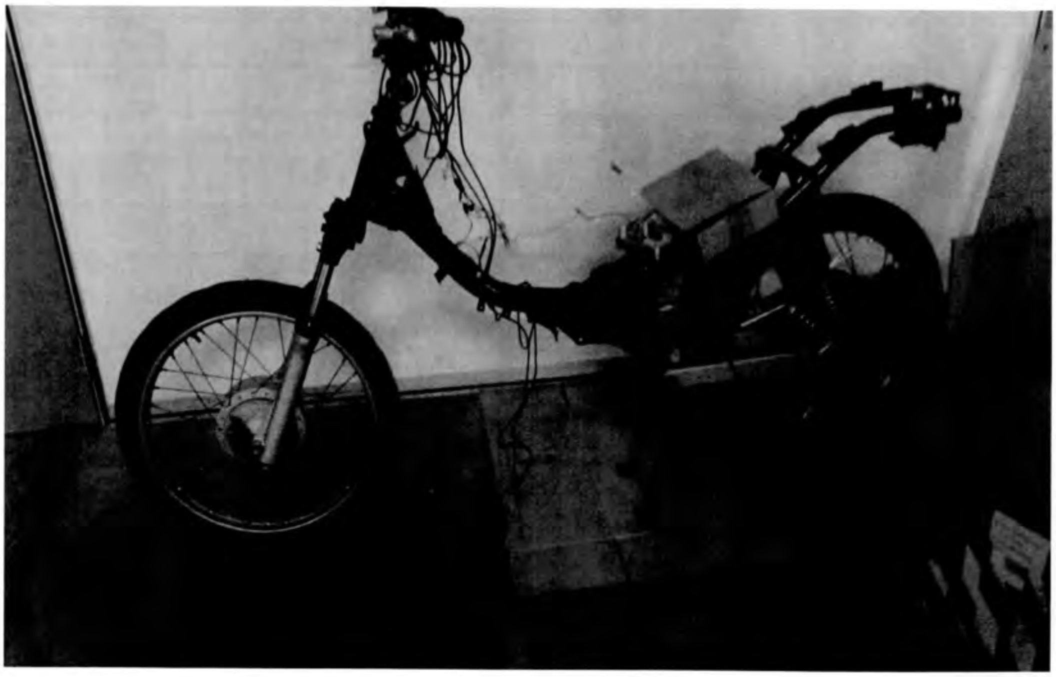


Fig.5.2.5: Assembly of Hub wheel motor and controller before laboratory testing

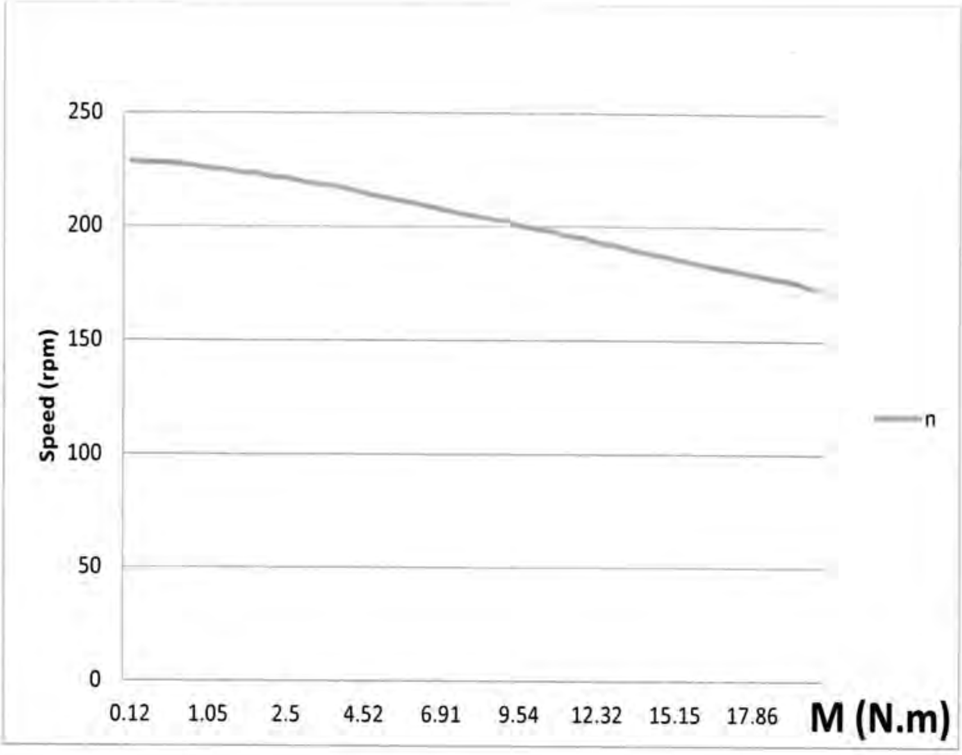
Table 5 below shows the test results on hub wheel motor. This test is performed by control the torque value and other parameters as in table 5 are recorded.

Table 5: Test results

Number	U	I	P1	M	n	P2	Eff
	V	A	W	N.m	rpm	W	%
1	47.6	0.629	22.66	0.12	228.5	2.96	13.0
2	47.6	0.786	28.33	0.19	228.2	4.53	16.0
3	47.6	0.768	27.67	0.25	228.1	6.16	22.2
4	47.6	0.784	28.27	0.35	227.6	8.53	30.1
5	47.6	0.955	34.41	0.65	226.6	15.46	44.9
6	47.6	1.239	44.62	1.05	225.5	24.97	55.9
7	47.6	1.370	49.35	1.29	225.1	30.59	61.9
8	47.6	1.569	56.51	1.54	223.8	36.27	64.1
9	47.6	1.749	63.00	1.84	223.4	43.22	68.6
10	47.6	1.969	70.92	2.18	221.8	50.76	71.5
11	47.6	2.228	80.27	2.50	221.4	57.99	72.2
12	47.6	2.480	89.36	2.87	219.6	66.17	74.0
13	47.6	2.697	97.14	3.25	218.5	74.44	76.6
14	47.6	2.997	107.9	3.65	217.8	83.32	77.1
15	47.6	3.260	117.4	4.08	216.4	92.48	78.7
16	47.6	3.552	127.9	4.52	214.5	101.6	79.4
17	47.6	3.860	139.0	4.97	213.0	110.8	79.7
18	47.6	4.168	150.1	5.43	211.6	120.4	80.2
19	47.6	4.471	161.0	5.92	210.4	130.4	80.9
20	47.6	4.795	172.7	6.41	208.9	140.1	81.1
21	47.6	5.125	184.6	6.91	207.5	150.1	81.3
22	47.6	5.445	196.1	7.41	205.8	159.7	81.4
23	47.6	5.789	208.5	7.95	204.7	170.4	81.7
24	47.6	6.135	220.9	8.46	203.6	180.4	81.6
25	47.6	6.490	233.7	8.99	202.3	190.4	81.4
26	47.6	6.834	246.1	9.54	200.3	200.1	81.2
27	47.6	7.189	258.9	10.10	199.0	210.4	81.2
28	47.6	7.542	271.6	10.63	197.9	220.2	81.0

29	47.6	7.885	284.0	11.19	195.9	229.6	80.8
30	47.6	8.248	297.0	11.74	195.0	239.6	80.6
31	47.6	8.613	310.2	12.32	193.0	248.9	80.2
32	47.6	8.970	323.0	12.86	192.0	258.5	80.0
33	47.6	9.334	336.1	13.45	190.4	268.1	79.7
34	47.6	9.688	348.9	14.01	188.9	277.0	79.4
35	47.6	10.05	362.0	14.55	187.6	285.7	78.9
36	47.6	10.44	376.0	15.15	186.1	295.1	78.4
37	47.6	10.78	388.5	15.72	184.6	303.8	78.2
38	47.6	11.14	401.4	16.28	183.3	312.4	77.8
39	47.6	11.49	414.1	16.81	181.9	320.2	77.3
40	47.6	11.83	426.4	17.34	180.6	327.9	76.9
41	47.6	12.17	438.5	17.86	179.4	335.5	76.5
42	47.6	12.52	451.1	18.40	178.1	343.1	76.0
43	47.6	12.87	463.5	18.93	176.9	350.6	75.6
44	47.6	13.23	476.5	19.47	175.5	357.8	75.0
45	36.00	13.53	487.4	20.03	172.9	362.5	74.3

From the data as in the table 5, graph 5.1 to 5.4 are then plotted to show the relation between the output current, output power and speed in rpm against torque in N.m.



Graph 5.1: Speed vs Torque

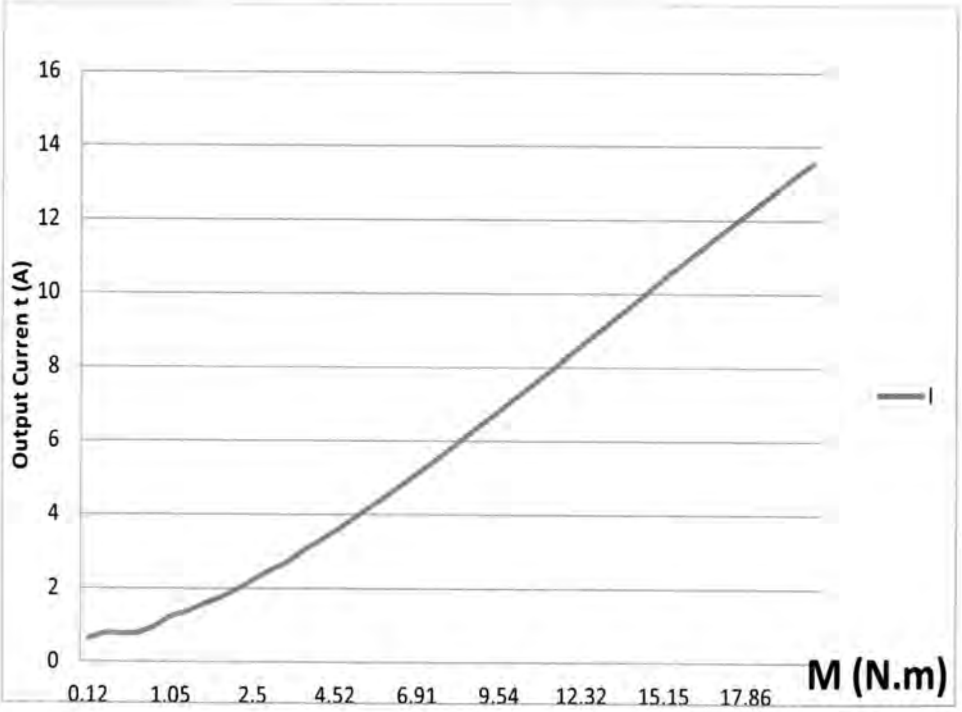


Fig.5.2: Output Current vs Torque

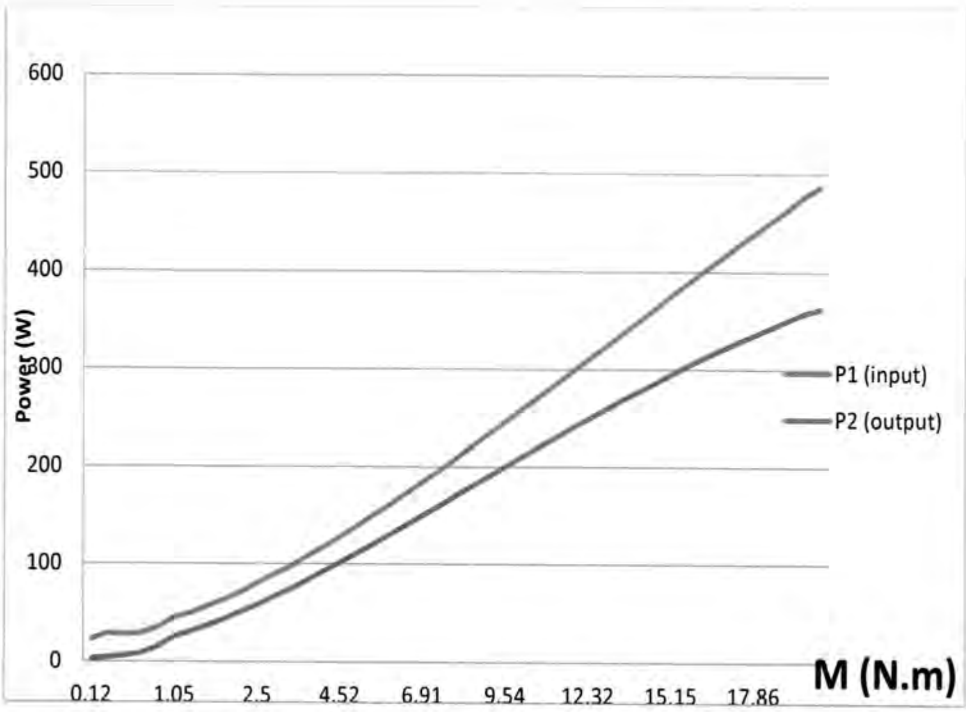


Fig.5.3: Input and Output power vs Torque

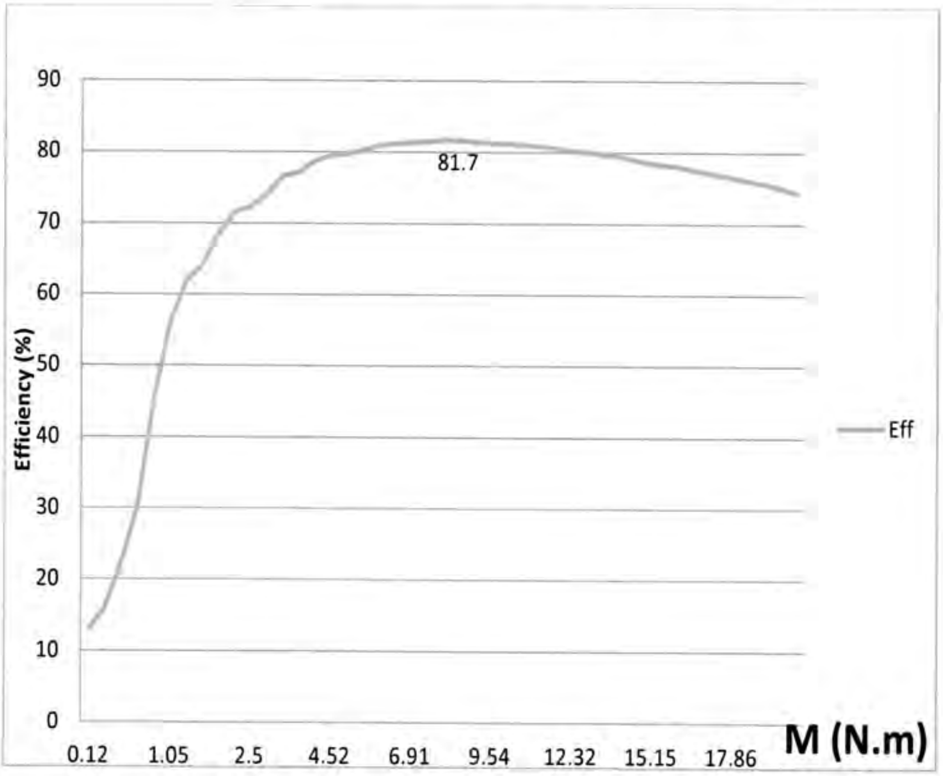


Fig.5.4: Efficiency vs Torque

The experiment results for the parameters and the torque capacity were compared with the results of the analysis by finite element software. The torque characteristics from the FEM analysis agreed well with those from the experiment.

6. Conclusion

The purpose of this project was to convert a gasoline powered motorcycle into an electric motorcycle. The practical aspects of converting a motorcycle with an internal combustion engine into an electric motorcycle have been demonstrated. The need for a heavy and energy inefficient transmission was negated by using a dc motor with an appropriate r.p.m./torque ratio in conjunction with a Pulse Width Modulator for speed control. The entire electrical system of the electrical motorcycle, including batteries, motor controller, wiring and casing is about 20 kg lighter than the original combustion engine system. A theoretical model was developed using the motor current, speed, torque curves, battery discharge curve and pertinent motorcycle's data. The model provides information regarding range, top speed and acceleration. The accuracy of the model was demonstrated by field tests, once the motorcycle design was completed.

7. REFERENCES

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