Modified Microcontroller Based Hybrid Electric Rickshaw as a sustainable means of transportation for Nepal

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Abstract: Rickshaw, a small scale low cost, local means of transport used in some part of Nepal especially plain belts and cities requires a lot of human effort and time in pulling which increases the working hours for travelling the particular distance thereby reducing the income of rickshaw puller. Most of the drivers are only male and elderly person and in some cases they are found to be drunk while driving to get relief from pain which makes the travel really unsafe. Moreover e-vehicles commonly used in southern belts of Nepal costs around 5000$ which is unaffordable for low class families and rickshaw drivers. Microcontroller based hybrid e-rickshaw the modified version of conventional rickshaw can overcome the problems associated with the conventional one.

Micro controller based hybrid e-rickshaw is a battery powered, hybrid three-wheeler with provisions of dual drive system either from paddle or electric motor. Micro Controller is used to control the speed of the rickshaw using accelerator which works on the principle of speed control using Pulse Width Modulation (PWM) technique. The micro controller is also used to prevent the supply from the battery when the battery reaches its Depth of Discharge (DOD) in order to prevent it from being damage thereby increasing the lifecycle of the battery. The feature of hybrid system allows the travellers to reach the required destination whenever the battery is fully dead using the paddling system. Moreover braking switch is provided with controller applying the electrical brake to gain the rapid stop of the motor. The electric rickshaw is designed at top speed of 15 km/hour on the plain road with two passengers on board and can also operate at 10 degree slope.

The designed e-rickshaw which increase the comfortness and reduce human effort decreases the working hours for travelling particular distance and thus uplifting the socio-economic condition of the rickshaw pullers can eliminating the problem of drunk and drive too. This cheapest e-rickshaw which cost around 1500$ will encourage women and economically weak families for driving thereby empowering the involvement of women and financially backward people in employment.

Keywords: E-rickshaw, E-vehicle, Conventional Rickshaw, Permanent Magnet Direct Current, Hybrid, Pulse width modulation, Grid, Battery powered, Depth of discharge

1. Introduction

For the past few decades it was common to see conventional rickshaw in various cities in Nepal. Most widely it is operated in flat land like Kathmandu valley, Pokhara valley and southern cities of Nepal, but for past years due to increased traffic in hilly cities, conventional commercial rickshaw operation became quite unpopular and now it is only limited in southern cities of Nepal. And in the context of southern cities due to continuous ascension inflation rate in monitory economy of Nepal, rickshaw business is now under the threat of diminishing. Along with it, rickshaw pullers are shifting towards other income generating activities since effort required to pull rickshaw is higher and relative to effort the income generated by rickshaw pullers is nominal. This problem had adverse effect on rickshaw puller's business as well which has diminishing percentage of almost 61% according to General Federation of Nepalese Trade Union (GEFONT).

For the past years due to rise in inflation rate many low-income people are losing their daily business and among which rickshaw pullers are in great numbers. According to the survey done in Chitwan among the rickshaw owner 7 out of 10 rickshaw owners are forced to shut down their business because of less people getting motivation to pull rickshaw and due to the new rising trend in business. Since rickshaw pulling job requires a lot of manual effort (peddle power), it pays back very limited amount compared to the effort it requires. Not only were this but also conventional rickshaw pullers found drunk to be free from pain while pulling rickshaw. Therefore, rickshaw pullers

need an alternative to raise their economic status within the society to address the economic threat and to address their daily basic needs. Some rickshaw owner who used to have more than 20 rickshaws at their company purchased E-Rickshaw to sustain their business but due to its backup failure it is not a sustainable solution to the ground problem.

Introduction of the E-Hybrid rickshaw however can be of great use to address the problem of rickshaw pullers, owners and passengers as well. Since passengers in rickshaw get facility to be picked and dropped at their house or their preferred location, these vehicles had been people's preference. Upgraded rickshaw will be convenient for pullers to pull easily with extra function of increasing the speed with less effort and control mechanism to control the rickshaw. This comes with simple technic to which puller will find easy to use. By the help of this upgraded rickshaw, pullers can make several trips in a day and can earn more money than in conventional rickshaw with the usage of less effort. Passenger for rickshaw has long history of riding conventional rickshaw. For many passengers, it was easy to be dropped at exact location to which current E-rickshaw and other auto rickshaw doesn't address this need.

2. Existing Tricycle Scenario

The number of owner varies in southern Nepal as the convenient and traditional means of transportation is rickshaw. According to General Federation of Nepalese Trade Union (GEFONT) who are registered as a member in Nepal Rickshaw Pullers Union are 6170 in number. These rickshaw owners own minimum of 5 rickshaws to maximum around 20 rickshaws. This gives rough information to minimum of 30,850 to maximum approximately 123400 around the country.

However, the existing rickshaws are so poorly designed that running them takes a heavy toll on the health of a rickshaw puller. The gearing and the mechanical advantage of the pedal is very poor. Hence the rickshaw puller has to work very hard while climbing even a slight slope. The braking system is also very poor with only front brakes on the rickshaw. Thus when going downhill at high speeds sudden braking produces catapults affect which results in overturning of the rickshaw. Similarly the seating arrangement is very uncomfortable and the aerodynamic drag of the system is very high. There are estimates that rickshaw pulling is far more stressful than even hard labor Thus

there is a need to improve the existing rickshaw to make it user friendly and bring quality control in its manufacture.

Figure 1 Conventional Tricycle

3. Electrical model of a PMDC motor

Electrically, permanent magnet brushed DC motors can be modeled as a series of three basic electrical components: a resistor, an inductor, and a source of electro-motive force (EMF), or voltage. This voltage source is commonly called the "back-EMF" or "counter EMF." The origins of the resistive and inductive components are easy to see. The resistor in the model is a result of the finite resistance per unit length of wire used to construct the coils in the armature. The inductor is a result of coils of wire that make up the armature windings. All coils of wire act as inductors.
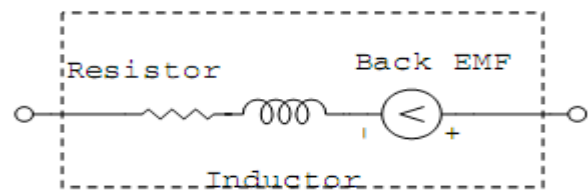

Figure 2 Electrical Model of a PMDC Motor

Characteristic constants for Permanent Magnet Brushed DC motors

As a motor turns faster, more back-EMF is generated since the coils in the armature are moving faster through the stator's magnetic field. The magnitude of the back-EMF is related to the rotational speed through a constant K_e, called the speed constant or voltage constant.

$$E_b = k_e\omega \quad [V], \qquad\qquad 1$$

Where E_b = back e.m.f in volts

k_e= voltage constant in volts per rad per sec

ω = rotational speed in rad per sec.

If the losses are negligible, then the mechanical power into the generator, $T\omega$, will equal the electrical power out, E_bI.

$$P = E_b I = T\omega \ [W] \qquad\qquad 2$$

Where T = Torque developed in N-m.
Combining equations 1 and 2 we get,

$k_e\omega I = T\omega$ that can be further simplified as,

$$T = k_e I \ [N\text{-}m] \qquad\qquad 3$$

Also, $T = k_t I \qquad\qquad 4$

Where k_t = Torque constant in N-m per ampere.

This distinction between k_t and k_e is particularly useful in that numerically $K_t = K_e$ when compatible units are used (e.g. N-m per ampere and volts per radian per sec).

Characteristic equations for constant voltage
To more fully understand the torque and speed characteristics of a motor we can start by examining what goes on when we place the motor into a circuit with a driving voltage.
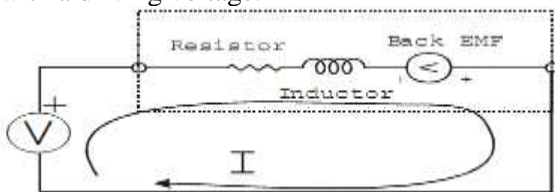

Figure 3 DC Motor circuit with driving voltage

Using Kirchhoff's laws to write a loop equation to describe the steady-state current flow in this circuit.

$$V = IR + k_e\omega \qquad\qquad 5$$

Where V = Applied voltage [V],
I = Current [A],
R = Resistance of motor coils [Ω]
k_e = Voltage constant [volts per rad per sec],
ω = rotational speed [rad per sec]

From equations 1, 4 and 5 we get,

$$\omega = \frac{V}{k_e} - \frac{RT}{k_t k_e}$$

This shows that for a given voltage V, torque and speed for a motor are linearly related. Thus speed can be controlled by varying the armature voltage.
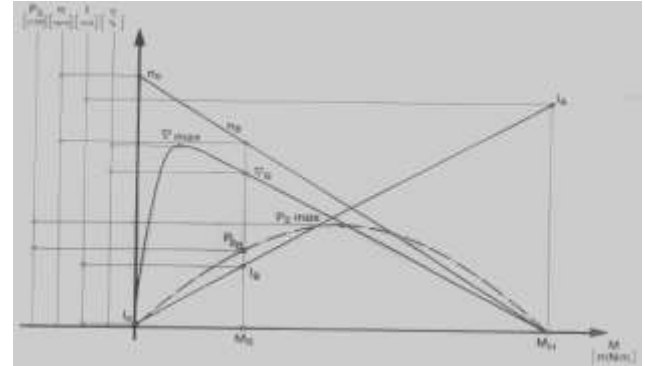
PMDC motor characteristics

Figure 4 Composite DC motor characteristics, showing the interrelationship between efficiency η, torque M, current I, speed n, and power P for a given voltage

4. Modified Microcontroller Based Hybrid Electric tricycle
Micro controller based hybrid E-Rickshaw includes system with both paddle and electricity driving mechanism. The process of development includes modifying conventional rickshaw by incorporating PMDC motor and Battery with separate gear system. The speed can be controlled using accelerator. It will have smooth speed control with PWM control, electrical braking system. The maximum speed of 15 km/hour at 10 degree slope with no passenger on board. It Can Carry Three Persons on board including driver.
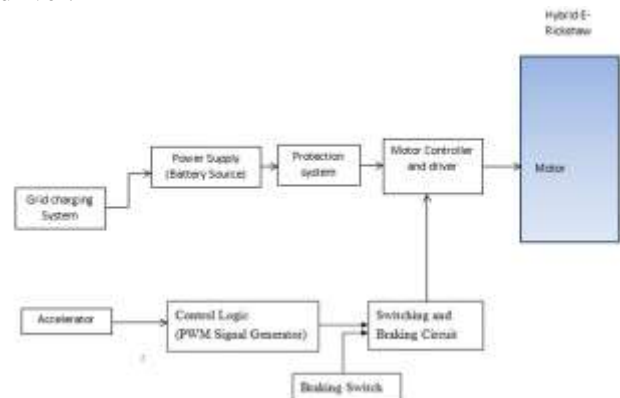

Figure 5 Overall block diagram

5. Mathematical Modeling
A. Motor Selection
Rickshaw weight = 60 kg
D.C Motor = 10 kg
Battery (4x 15) = 60 kg
Other Parts (Speed Controller, Power Transmission System) = 15 kg
Pay load = 140 kg (2 person + extra load)
Rickshaw puller = 70 kg
Total Weight = 335 kg
Velocity of the rickshaw = 15 kmph = 4.16 m/s

1) Road Resistance:
For vehicle running on "Hard Dry Clay" = 430 N/1000 kg=0.43 N/kg
F_r = 335 kg x (0.43)
= 144.05 N

2) Acceleration force required:
Considering the time taken for full acceleration to be 10 sec
F_a = ((4.16 – 0)/10) x 335 = 139.36 N

3) Force requirement to overcome the slope:
Considering 11° slope to overcome

F_s = tan 11.3^o x 335 x 9.81 = 657.27 N

4) Air Resistance

F_{air} = 0.045x (3 m^2) x (4.16^2) = 3N
0.045= coefficient of air resistance
3 m^2 = Area of rickshaw facing against the velocity of wind.

Therefore the maximum force required to drive the rickshaw is 943.68 N.
To drive the rickshaw on plane road, force average= 286.41 N

5) Mechanical Torque requirement :
T max = total force x radius of the back sprocket = 943.68 x 0.05
= 47.184 Nm (maximum)
Tavg = 286.41 x 0.05
= 14.32 Nm

6) R.P.M required for wheel(N):

Considering the rpm of the back sprocket and wheel to be same.
Velocity = 4.16 m/s
Radius of wheel (r) = 0.33 m
Velocity = 2 x pie x N x r
4.16x60 = 2 x pie x N x 0.33
Therefore N = 120 rpm.

7) Power Required:
Maximum Power required, P= (2 x pie x N x Tmax)/ 60
= (2 x 3.14 x 120 x 47.184) / 60
= 592.93 watts
Average Power required
P = (2 x pie x 120 x 14.32) /60
= 179.95 watts

Considering 20% loss in power transmission

Maximum Power required,
P = 592.93+ 20% x 592.93=711.51 watts
Considering 20% loss in power transmission
Average Power required,
P = 179.95+ 20% x 179.95
= 215.94 watts

Findings

Maximum power required = 712 watts
Average power required = 216 watts
Maximum torque required= 57 nm

(Considering 20% loss)

Average torque required=17 nm
R.P.M required for rickshaw = 120

B. Battery Bank sizing

Table 1 Battery Bank Sizing

Battery Bank Sizing	
Days of Autonomy	1
Battery Bank Voltage	48
Minimum Storage Needed (Ah)	48
Individual Battery Voltage	12
Individual Battery Size	65
No. of Batteries (of Bank Voltage)	1
No. of Batteries (Actual)	4
Battery Bank Capacity at Bank Voltage(Ah)	65
Battery C-Rating	20
Paths in parallel (should be 5 or less)	1
Max current discharge (A)	3.25
Max power output (KW)	0.14

For a 48 volts system, 4 batteries each of 65 Ah are connected in series to power the 800 watt PMDC motor. These batteries can operate continuously for 6 hours at full load with daily charging requirement of 7-8 hours.
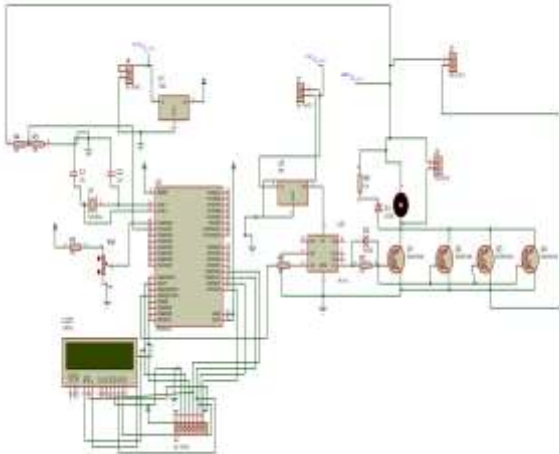
C. Speed controller

Figure 6 Speed controller

The accelerator works as a potentiometer for supplying variable voltage to the micro controller so as to generate PWM signal to control the speed of motor. The power supply to the motor is supplied from the battery through 4 parallel connected IGBT in order to increase the current rating of the controller. The controller will also have a protection system to cut the power off if the battery reaches below its prescribed charge limit. The display will show the speed and voltage level of the battery.
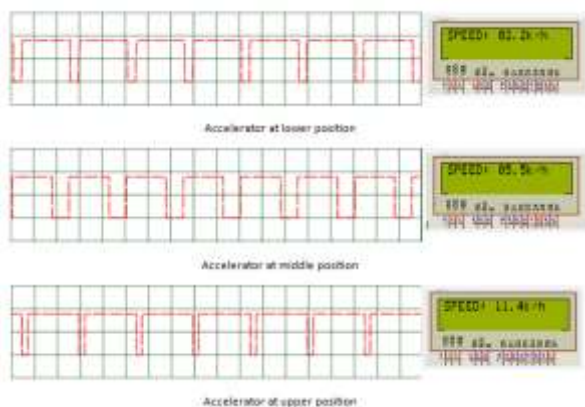

Figure 7 PWM signal

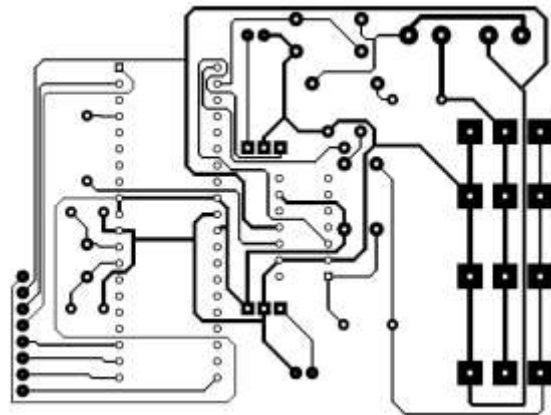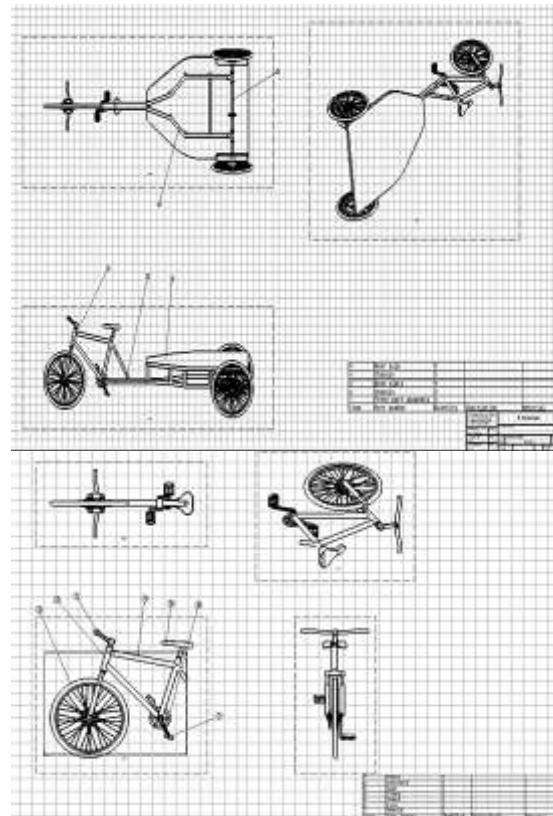The PCB layout of the controller is as shown in the figure 8

Figure 8 PCB layout of controller

D. Mechanical Design

The weight of the rickshaw is around 60 kg with tyre to tyre width of 42inch at rear and total length of 93 inch. The diameter of tyre is 27 inch giving the ground clearance of 27 inch.
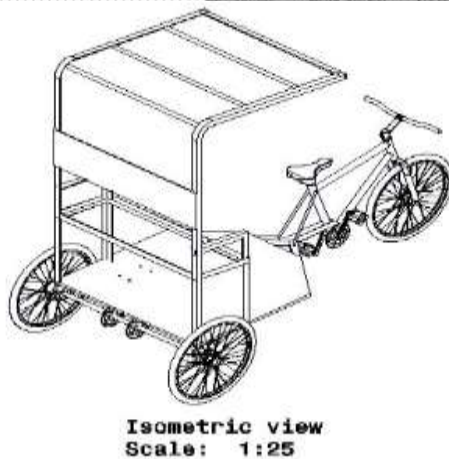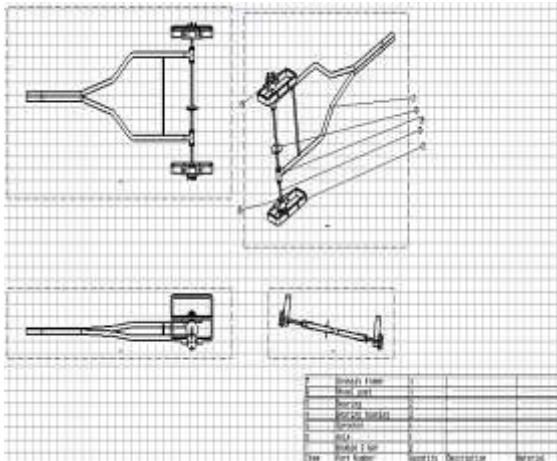
Figure 9 Assembly of E- Rickshaw

Figure 10 Experimental Setup for acquiring motor characteristics.

Experimental Results:

Table 2 Experimental results of a blocked rotor test performed at reduced voltage

Vr (V)	Ia (A)	Pin (W)	I²R loss (W)	Speed (rpm)	Speed (rad/s)	Efficiency	Shaft power (W)	Load torque (N-m)
36	1.15	41.40	1.59	954	99.90	0.96	39.81	0.40
35.4	1.3	46.02	2.03	934	97.81	0.96	43.99	0.45
34.8	1.54	53.59	2.85	898	94.04	0.95	50.75	0.54
33.7	2.4	80.88	6.91	847	88.70	0.91	73.97	0.83
31.9	3.8	121.22	17.33	769	80.53	0.86	103.89	1.29
30.8	4.47	137.68	23.98	733	76.76	0.83	113.70	1.48
30	5	150.00	30.00	696	72.89	0.80	120.00	1.65
29	5.8	168.20	40.37	668	69.95	0.76	127.83	1.83
28	6.5	182.00	50.70	633	66.29	0.72	131.30	1.58

6. Result analysis

Speed of the tricycle is controlled smoothly with the newly developed controller which also indicates the speed and voltage level of the motor and the battery. The warning is also given to the driver when the battery is in need of charging. From the analysis we found the information as described below.

Testing of a PMDC motor:
Blocked rotor test was performed in the lab by coupling a PMDC motor with electromagnetic braking system. The experimental setup and results are shown below.
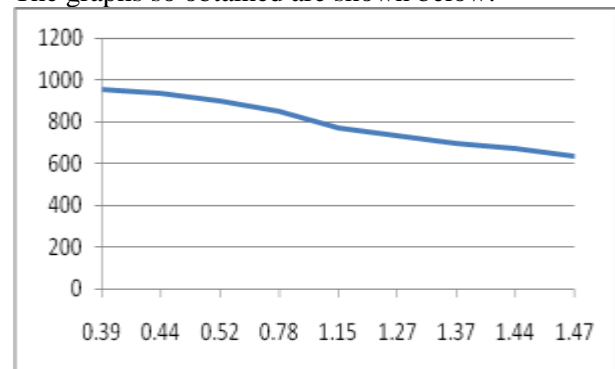
The graphs so obtained are shown below:

Figure 11 Speed Vs Torque characteristic
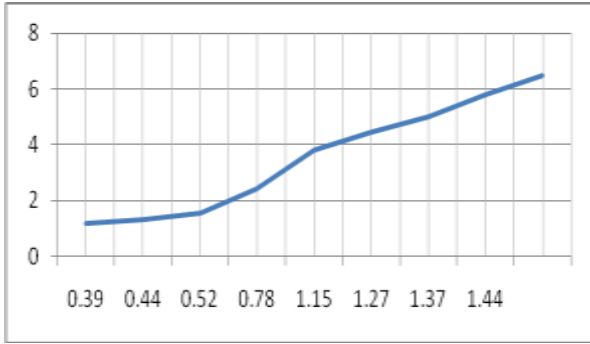
(X-axis: Torque Nm & Y-axis Speed rpm)

Figure 12 Armature Current Vs Torque characteristic
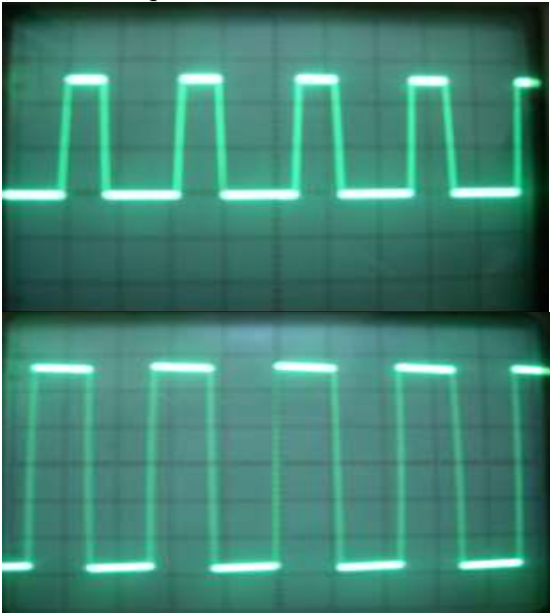
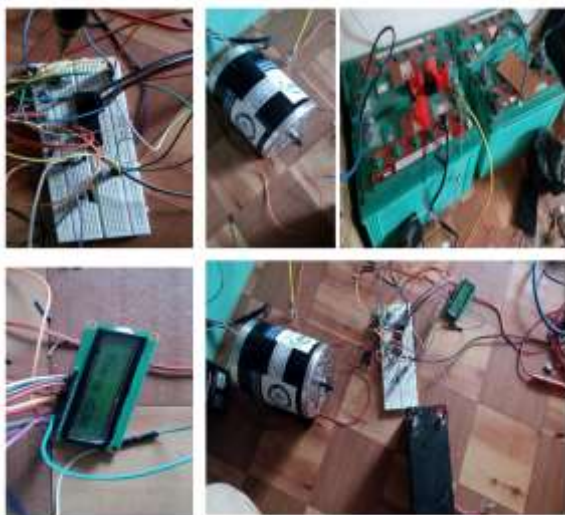*(X-axis: Torque Nm & Y-axis: Armature Current)*

Figure 13 PWM signal waveform

Figure 14 Controller circuit

Figure 15 Mechanical assemble of modified Rickshaw

Table 3 Main findings

	Specification
Mileage	70KM per charging
Total Load	350-400 Kg
Charging time	**6-7 hours**
Motor	48Volt, 800 watt PMDC motor
Battery bank	80-100Ah , 48 Volt
Speed Controller	80A, 48 Volt DC
Charger	220Volt, 50 Hz/ 20A, 48 Volt DC
Top Speed	**15 km/h**

7. Conclusion

The designed e-rickshaw increase the comfortness and reduce human effort and decreases the working hours for travelling particular distance and thus uplifting the socio-economic condition of the rickshaw pullers hence eliminating the problem of drunk and drive too. This cheapest e-rickshaw which cost around 1500$ will encourage women and economically weak families for driving thereby empowering the involvement of women and financially backward people in employment.

8. Acknowledgement

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