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Design and Development of Electrical Powertrain of ATV

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Abstract - *Air pollution has become a major concern in the recent years and a dominant area contributing to air pollution is automobile industry. It is known that petrol and diesel vehicles are not a part of foreseeable future and electric/hybrid vehicles provide a promising solution to the above problem. The design competition of eBAJA SAE (Society of Automotive Engineers) INDIA represent students a challenge to design, engineer, test and promote an electrical driven ATV (All-terrain vehicle) within the constrain of the rules of SAE India. Mathematical study, designing and analysis of the system is done in accordance to the national ATV design competition organized by BAJA SAE India 2019. Considering off road conditions, various test conditions are incorporated which are: different impact tests, brake test, acceleration and traction test to get the design parameters, around which designing is done by the team for the ruggedness over rough terrain with reliable and robust performance in a cost effective manner.*

***Key Words*: Tractive effort, All Terrain Vehicle, Hall Effect, Pulse Width Modulation (PWM), DC-DC converter**

1. INTRODUCTION

Electric vehicles are growing in popularity as they prove to be cleaner and more energy efficient in comparison to the conventional vehicles. EVs provide 75% efficiency in turning the input energy to kinetic energy whereas gas powered vehicles are only 25% efficient. This project aims at the design, analysis and optimization of an electric ATV.

ATV which is the acronym for All Terrain Vehicle, is capable to run in all types of non-motorable rough terrains having obstacles like rocks, sand, mud, steep inclines, and shallow water. The vehicle must be able to sustain all the loads that are generally encountered in an off-road scenario both static and dynamic and should possess enough traction to overcome resistance encountered in the off-road scenario. The dynamic stability and ride throughout the uneven rough terrain is also a major consideration for the design of an ATV.

1.1 POWERTRAIN

The power train of ATV which includes BLDC motor, controller, battery and transmission, is a vital part of the vehicle; it is such selected and designed that it provides the required tractive effort as well as acceleration under restricted speed conditions. Given specified rated BLDC motor should not exceeds of 6KW,together with of battery 48V,110 Ah Li-ion battery (as per the rules of competition), space constraints and the various conditions of terrain type, a suitable transmission system is selected its parameters are designed, which is largely responsible for major vehicle performance parameters

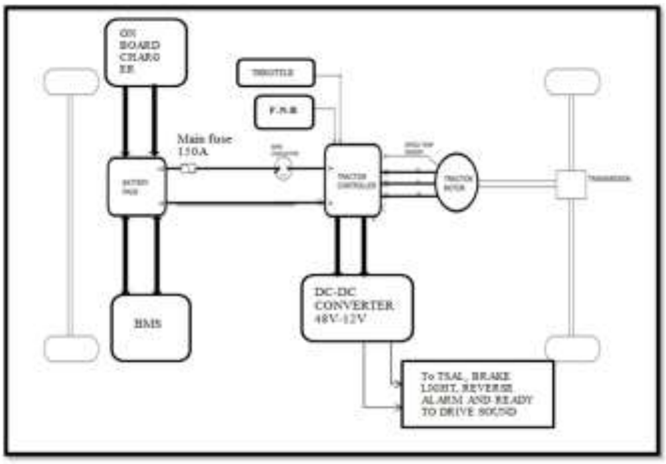

Fig -1: Block diagram of electrical powertrain

2. STUDY OF MOTOR

The speed and torque characteristics of brushless DC motors are very similar to a shunt wound "brushed" (field energized) DC motor with constant excitation. As with brushed motors the rotating magnets passing the stator poles create a back EMF in the stator windings. When the motor is fed with a three phase stepped waveform with positive and negative going pulses of 120 degrees duration, the back EMF or flux wave will be trapezoidal in shape.

2.1 Synchronous Operation

Brushless DC motors are not strictly DC motors. They use a pulsed DC fed to the stator field windings to create a rotating magnetic field and they operate at synchronous speed. Although they don't use mechanical commutators they do however need electronic commutation to provide the rotating field which adds somewhat to their complexity.

2.2 Rotating Field and Speed Control

In the diagram below, pole pair A is first fed with a DC pulse which magnetizes pole A1 as a South Pole and A2 as a north pole drawing the magnet into its initial position. As the magnet passes the first magnetized pole pair, in this case poles A1 and A2, the current to pole pair A is switched off and the next pole pair B is fed with a similar DC pulse causing pole B1 to be magnetized as a south pole and B2 to be a north pole.

The magnet will then rotate clockwise to align itself with pole pair B. By pulsing the stator pole pairs in sequence the magnet will continue to rotate clockwise to keep itself aligned with the energized pole pair. In practice the poles are fed with a polyphase stepped waveform to create the smooth rotating field.

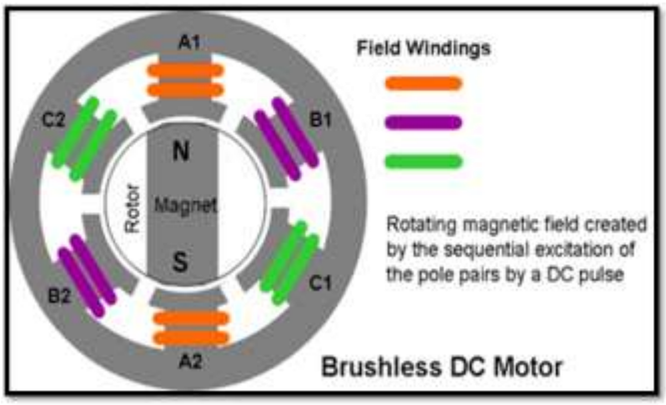

Fig -2: Rotating field operation of BLDC motor

A six step inverter is used to generate the three phase supply and the electronic communication between the three pairs of stator coils needed to provide the rotating field. Only two out of three pole pairs are energized at any one time. This also means that only two of the six inverter switches are conducting at any one time. See the Motor Control diagram below. The speed of rotation is controlled by the pulse frequency and the torque by the pulse current. In practice the system needs some fairly complex electronics to provide the electronic commutation.

2.3 Position Sensing and Speed Control

The inverter current pulses are triggered in a closed loop system by a signal which represents the instantaneous angular position of the rotor. The frequency of the power supply is thus controlled by the motor speed.

Rotor position can be determined by a Hall Effect device (or devices), embedded in the stator, which provide an electrical signal representing the magnetic field strength. The amplitude of this signal changes as the magnetic rotor poles pass over the sensor.

The diagram below shows the system for controlling the voltage and speed with the associated current and voltage waveforms superimposed on the circuits.

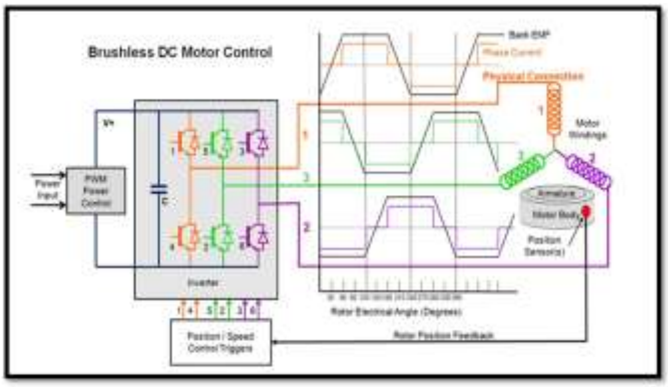

Fig -3: Position sensing and speed control of BLDC motor

Note that though the magnetizing current pulses are in the form of a stepped square wave, the back EMF is in the form of a trapezoidal wave due to the transition periods as the rotor magnet poles approach and diverge from the stator coils when the rotor magnet is only partially aligned with the stator magnets. Power management is usually by means of a pulse width modulated controller (PWM) on the input supply which provides a variable DC voltage to the inverter.

3. STUDY OF KELLY CONTROLLER

Modern controllers may incorporate both power electronics and microprocessors enabling the controller to take on many more tasks and to carry them out with greater precision. These tasks include:

• Controlling the dynamics of the machine and its response to applied loads. (Speed, torque and efficiency of the machine or the position of its moving elements.)
• Providing electronic commutation.
• Enabling self-starting of the motor.
• Protecting the motor and the controller itself from damage or abuse.

• Matching the power from an available source to suit the motor requirements (voltage, frequency, number of phases). This is an example of "Power Conditioning" whose purpose is to provide pure DC or sine wave power free from harmonics or interference. Although it could be an integral part of a generator control system, more generally, power conditioning could also be provided by a separate free standing module operating on any power source.

One of the major attractions of brushed DC motors is the simplicity of the controls. The speed is proportional to the voltage and the torque is proportional to the current.

Speed control in brushed DC motors used to be accomplished by varying the supply voltage using lossy rheostats to drop the voltage. The speed of shunt wound DC motors can also be controlled by field weakening. Nowadays electronic voltage control is employed.

Simple open loop voltage control is sufficient when the motor has a fixed load, however open loop voltage control cannot respond to changes in the load on the motor. If the load changes, the motor speed will also changes. If the load is increased, the motor must deliver more torque to reach an equilibrium position and this needs more current. The motor consequently slows down, reducing the back EMF so that more current flows.

To maintain the desired speed, a change in the voltage is needed to provide the necessary current required by the new load conditions. Automatic control of the speed can only be accomplished in a closed loop system. This uses a tacho generator on the output shaft to feedback a measure of the actual speed. When this is compared with the desired speed, a "speed error" signal is generated which is used to change the input voltage to the motor to drive it towards the desired speed. Note - This is essentially a control system since the tach generator usually provides a DC voltage output which is compared with a reference input voltage.

Voltage control alone may be insufficient to cater for wide, fast changing load conditions on the motor since the voltage controller may call for currents in excess of the motor's design limits. A separate current feedback loop may be required to provide automatic current control. The current control loop must be nested within the voltage control loop. This allows the voltage control loop to deliver more current but it cannot override the current control which ensures that the current remains within the limits set by the current control loop.

Brushless DC motors are powered by a pulsed DC supply to create a rotating field and the speed is synchronous with the frequency of the rotating field.

Kelly controller KLS7245HC is used for the controlling action of ATV. It works on the PWM. The below wiring diagram show the connection of various components in ATV.

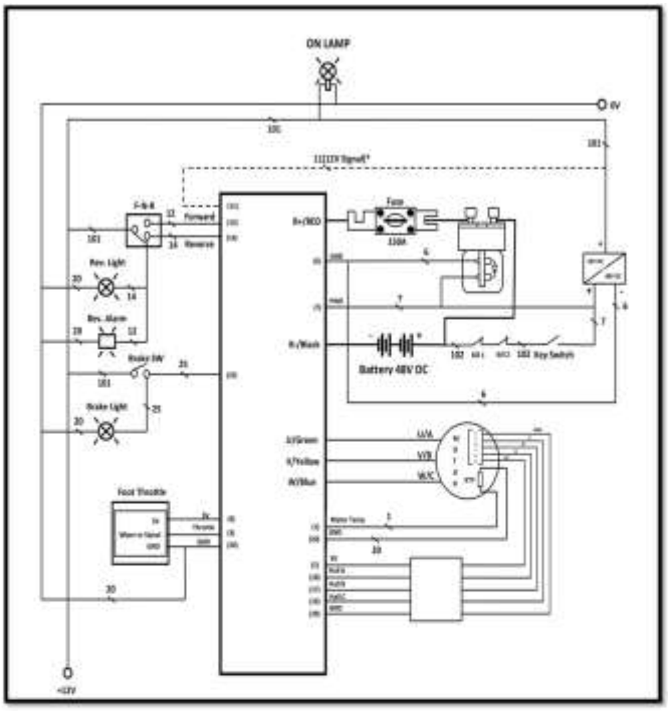

Fig -4: Kelly Controller connection diagram

4. CALCULATIONS AND ANALYSIS

4.1 DATA

Mass of vehicle (M) = 280 kg
Weight of the vehicle (W) = M g
Acceleration due to gravity (g) = 9.81 m/s2
Gradient (inclination) (Ɵg) = 450
Density of air (ρ) = 1.29 kg/m3
Air drag coefficient (Cd) = 0.5
Frontal area (A) =1.0023 m2
Wheel radius(r) =0.2921m
Transmission efficiency (η) =85%

4.2 Vehicle Resistance

Resistive force offers resistance to vehicle's motion. There are different types of vehicle resistance acting on vehicle –

- **Rolling resistance**
- **Air drag resistance**
- **Gradient resistance**

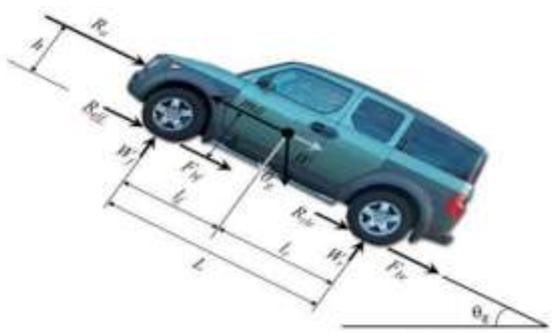

Fig -5: Vehicle Resistance

a) Rolling resistance - It is the friction force resisting the motion when a body (tire) rolls on a surface (road). This force acts at tire of vehicle and composed primarily of

- Resistance from tire deformation (~90%)
- Tire penetration and surface compression (~ 4%)
- Tire slippage and air circulation around wheel (~ 6%)
- Wide range of factors affect total rolling resistance and given by:

$$R_{rl} \text{ or } F_r = \mu r \times W \cos\Theta_g$$

b) Air drag resistance - A vehicle traveling at a particular speed in air encounters a force resisting its motion. This force is referred to as aerodynamic drag and composed of:

- Turbulent air flow around vehicle body (85%)
- Friction of air over vehicle body (12%)
- Vehicle component resistance, from radiators and air vents (3%) and

Air drag is given by:

$$\mathbf{F_A = ½\, C_d\, A\, V^2}$$

Where,
V – Velocity of the vehicle
A - Frontal area of vehicle
Cd- Drag coefficient

c) Gradient resistance - When a vehicle goes up or down a slope, its weight produces a component, which is always directed to the downward direction, as shown in figure. In vehicle performance analysis, only uphill operation is considered. This grading force is usually called grading resistance. The grading resistance, can be expressed as

$$Fg = W \sin\Theta g$$

4.3 Tractive effort

Tractive effort is the force required to keep the vehicle in motion. It is generated by engine. It should be more than the total resistance force to move the vehicle from rest. And this force is given by

$$F_t = (T_e \times i_g \times \eta)/r$$

Where
Te – torque developed by engine
ig - over all gear ratio now
Ft - *total resistive force*

4.4 Characteristics curve

Table -1: Characteristics curve for 4500 watt Nominal 4500 RPM motor

Torque (Nm)	Speed (RPM)	Input Current	Input Power	Output Power	Efficiency
9.6	300	8.10	388.8	271.30	69.78
9.6	450	12.30	590.4	415.08	70.31
9.6	750	26.40	1267.2	929.19	73.33
9.6	1350	37.80	1814.4	1355.12	74.69
9.6	1950	52.35	2512.8	1939.77	77.32
9.6	2550	59.85	2872.8	2306.02	80.27
9.6	3150	68.70	3297.6	2848.61	86.38
9.6	3600	75.30	3614.4	3255.55	90.07
9.6	4050	83.85	4024.8	3662.50	91.00
9.6	4500	93.75	4500	4191.52	93.14

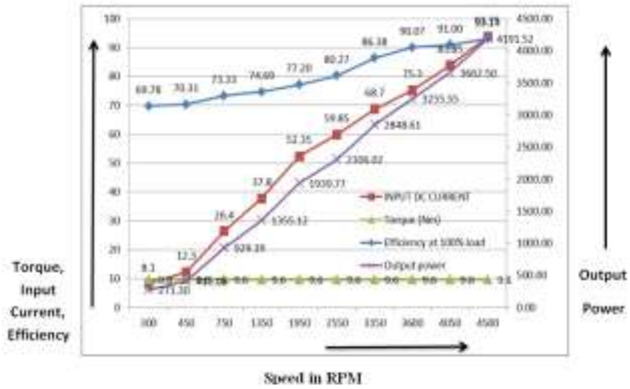

Chart -1: Characteristics curve for 4500 watt

Table -2: Characteristics curve for 6000 watt Nominal 4500 RPM motor

Torque (Nm)	Speed (RPM)	Input Current	Input Power	Output Power
12.7	300	10.2	489.60	327.00
12.7	450	17.5	840.00	508.44
12.7	750	35.2	1689.60	837.44
12.7	1350	49.3	2366.40	1615.06
12.7	1950	67.3	3230.40	2332.86
12.7	2550	78.5	3768.00	3050.67
12.7	3150	92.5	4440.00	3768.47
12.7	3600	101.3	4862.40	4306.82
12.7	4050	113.2	5433.60	4845.18
12.7	4500	125	6000.00	5443.35

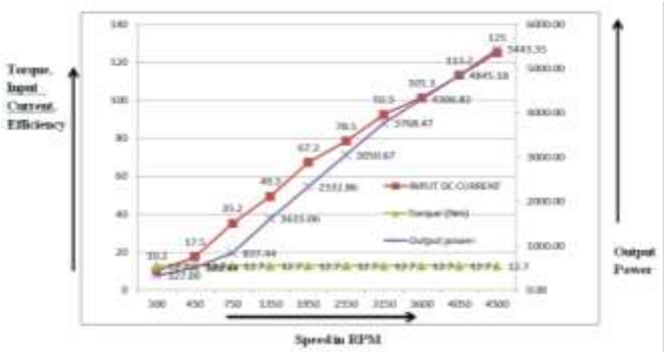

Chart -2: Characteristics curve for 6000 watt

5. CONCLUSIONS

As green vehicles continue to grow in popularity, automakers and scientists expect the brushless DC motor to dominate the market. With continuing innovations in electric car manufacturing, economists predict that by the year 2020, up to 33% of new car purchases worldwide will be for green cars.

But brushless DC motor isn't without fault. It's currently more expensive to manufacture than its brushed counterparts. Also, the magnetic field produced by the permanent magnets isn't adjustable. The strength of the magnetic field more adjustable so when an electric vehicle requires maximum torque, particularly at low speeds, the magnetic field will be at maximum strength.

As per the new research, using silicon as a cathode in cell, increase discharging time and also maintain efficient working at high temperature. Less options for efficient Battery management System in Indian market remain a cause using a less efficient BMS in system.

The regenerative braking is one of the important system in electric vehicles generation. The regenerative braking has the ability to save the waste energy up to 8-25%. The regenerative braking system improved by the advanced technologies of power electronic components, are ultra-capacitor, DC-DC converter.

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