DEVELOPMENT OF A SOLAR ELECTRIC HYBRID VEHICLE

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1. PROJECT OUTLINE

1.1 INTRODUCTION

India is densely populated and has high solar insolation, which varies from 4 to 7 kWh/ (m^2.day) with about 1500–2000 sunshine hours per year. Transportation sector is a major source for global carbon emissions and also contributes to air quality concerns, particularly in urban areas. In view of above, development of a passenger solar electric hybrid vehicle program has been initiated. The team is currently working towards the development of a solar passenger electric hybrid vehicle with an aim to reduce environmental pollutants by incorporating innovative energy efficient green technologies.

The broad objectives of this project will be to

- ✓ Reduce dependency on fossil fuels, to preserve environment through sustainable mobility solutions, and
- ✓ To penetrate Solar Hybrid Vehicle technology in the Indian Market at an affordable cost.

1.2 KEY FEATURES OF THE SOLAR HYBRID VEHICLE

The hybrid vehicle will be powered by a highly efficient electric drivetrain mechanism and the electric energy required to power the motor is being generated from a solar array and a gasoline powered genset which work in synchronization to deliver optimum performance, efficiency and dynamics. Technologies like plug-in and regenerative braking have also been incorporated in the vehicle.

Our aim is to develop a solar passenger electric hybrid vehicle that has been designed for strength, performance, weight, cost, safety, usability, tooling, quality, energy efficiency, recyclable and ease of assembly. The vehicle will be extremely practical and can be used for commuting on a daily basis. Efforts will be made to design the solar electric hybrid vehicle in a low cost manner in order to make it accessible for everyone.

1.3 WHY HYBRID?

We believe that the idea we have presented is the best one that can be implemented in practical very low carbon emission generating vehicles. Just using solar energy will be insufficient because of the many drawbacks we have in using such a system which use only solar array to charge the battery. Unless and until we increase the efficiency of our panels and reduce their size and cost as well (which will be there in future but it's very far from now), we cannot turn a pure solar electric vehicle into a practical general purpose model.

A pure electric car will also not work because of many drawbacks. The main drawbacks of Electric Vehicles are:

- High Operation Costs
- Low Reliability (batteries cannot last long and take many hours to get charged)
- High Initial Investment

<u>Electric vehicles have not been widely adopted because they are rather impractical!</u>
Electric cars also cannot cruise, accelerate, or climb fast enough to compete with gasoline-powered cars, and accessories, such as air conditioning and radios, drain the battery even further. Because electric cars are usually created by replacing the fuel tank and gasoline engine of a conventional car with electric motors, batteries, chargers, and controllers, the result is a car that is heavier and less efficient then a car solely running on electricity and more expensive because the manufacturer cannot fully recover the cost of the discarded parts

How the drawbacks are efficiently removed in hybrid cars:

- ✓ Using better quality batteries and components the period of battery replacement can be sufficiently elongated thereby reducing the operation costs
- ✓ The hybrid vehicles offer comparable reliability with those of petrol/Diesel cars.
- ✓ The initial investment can be lowered by mass production of cars.

Hybrid cars are often referred to as the 'Car of the Era'!

The advantages of the hybrid car start right from its difference in the basic pattern. Hybrid car is type of car that utilizes two energy sources for its movement. The popular hybrid cars in the market are manufactured in such a manner to combine the benefits of an internal combustion engine and electrical motor. The shortening level of gasoline in the world as it is a non-renewable energy was the major drawback of the conventional cars, which was rectified in the electrical cars, but it also had its own disadvantages.

The advantage of the hybrid car is that it can rectify the complaints in the both systems and balances the use of electrical energy and gasoline engine, in their optimum levels. The unique advantages of the hybrid car will be sole basis for such recognition in the market. The motor industry was always in the effort to develop most beneficial model and the disadvantages of the conventional model might be the triggering factor for the formation of advantageous models. Usually, anything to be considered as advantageous will make benefit only to its owner, and to the maximum, the family of the owner.

The specialty of the hybrid car enhances in this situation since its advantages can attribute benefit to not only the owner or his family, but to the entire society, nation and the mankind.

1.4 HOW IS SOLHYBRID DIFFERENT?

- ➢ The major advantage over Petrol/Diesel Cars is that it is more efficient and gives a better mileage apart from the fact being green.
- ➢ The dependability on Fossil Fuels as in normal Hybrids is reduced as Solar is playing a major role in charging of batteries during moving or while parking.
- ➢ The reliability factor that influences the consumer`s choice over choosing the electric vehicles due to range limitation is also sidelined due to the presence of an Auxiliary Diesel Engine which increases the range as well as reliability.

1.5 SOLHYBRID WILL BE WORLD FIRST, INDIA FIRST,

- ✓ Solhybrid will be India's first series hybrid passenger vehicle.
- ✓ Solhybrid will be the world's first hybrid which uses solar energy as a predominant source for power generation.
- ✓ Solhybrid will be the most affordable hybrid car in the fast growing Indian auto sector. Currently the only hybrid available in Indian market is Toyota Prius, priced at $50,000!

2. VEHICLE OPERATION

The vehicle includes the following powering/charging units:

- ✓ Solar charging unit (Solar Array + MPPT Change Controller)
- ✓ Genset powering unit (Genset + Rectifier)
- ✓ Battery powering unit (Battery pack + Buck/Bush Converter)

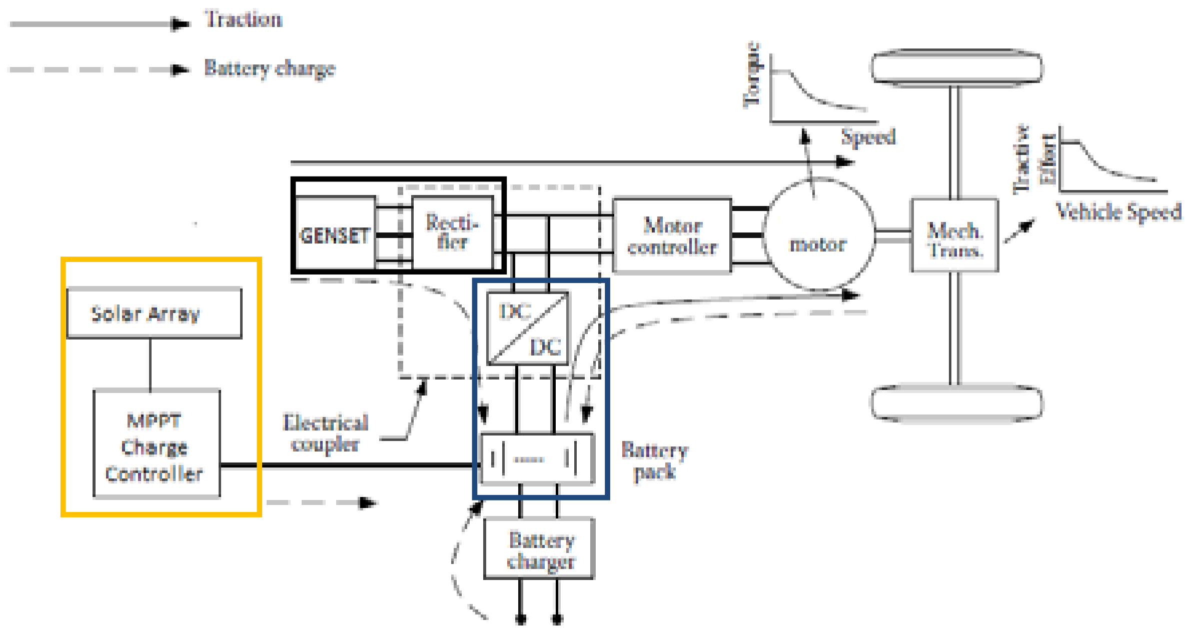

Fig 2.1: Block diagram of the vehicle's powering system.

The vehicle will be powered by a highly efficient electric drivetrain mechanism and the electric energy required to power the motor is being generated from a solar array and a gasoline powered genset which work in synchronization to deliver optimum performance, efficiency and dynamics. Technologies like plug-in and regenerative braking have also been incorporated in the vehicle.

2.1 VEHICLE OPERATION WHEN GENSET IS OFF

In this case, the only active powering unit will be battery powering unit. Batteries will be used to drive the motor and solar charging unit will be charging the batteries depending upon the amount of solar insolation that the solar arrays are receiving and the temperature conditions.

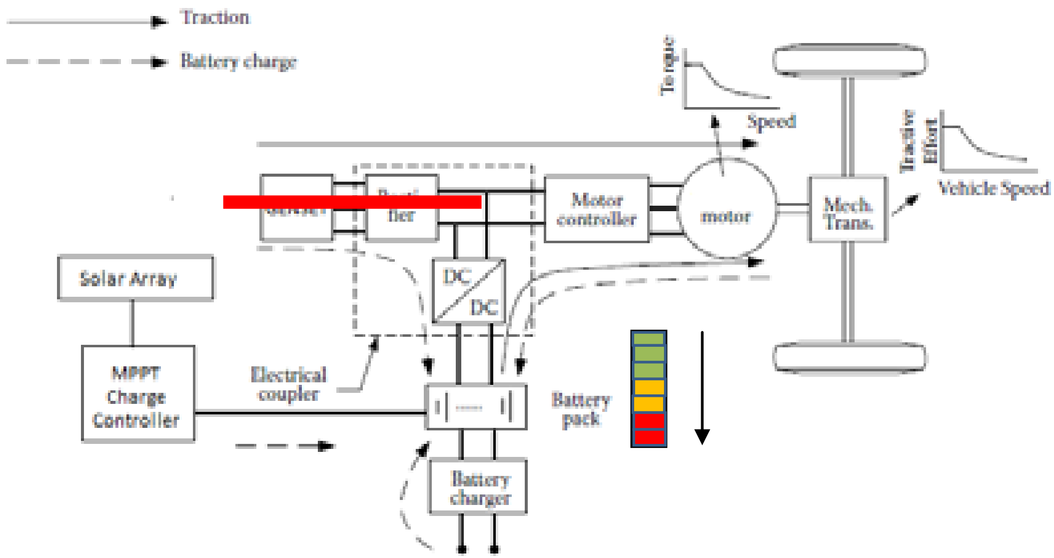

Fig 2.2: Vehicle operation when GENSET is OFF.

2.2 VEHICLE OPERATION WHEN GENSET IS ON

This would be the case when the battery pack is low. Genset will be the vehicle's powering unit in this case and will also be charging batteries along with the solar charging unit. The genset is automatically turned off once the batteries are fully charged and battery again becomes the vehicle's powering unit.

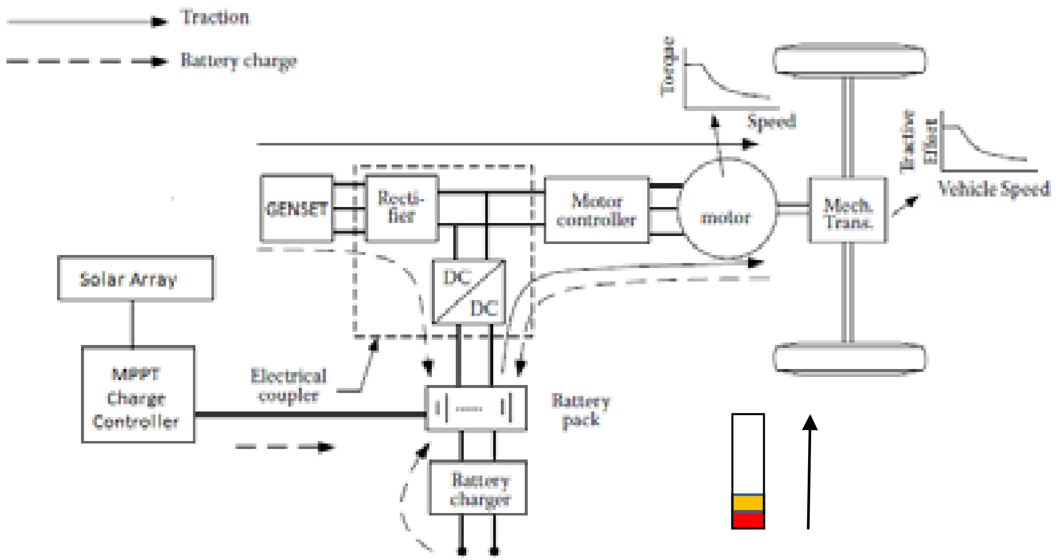

Fig 2.3: Vehicle operation when GENSET is ON.

2.3 ADVANTAGES OF SERIES HYBRID ELECTRIC DRIVETRAINS

- ✓ There is no mechanical connection between the engine and the driven wheels. Consequently, the engine can be potentially operated at any point on its speed-torque (power) map. This distinguished advantage, with a sophisticated power flow control, provides the engine with opportunities to be operated always within its maximum efficiency region. The efficiency and emissions of the engine in this narrow region may be further improved by some special design and control technologies, which is much easier than in the whole operating domain. Furthermore, the mechanical decoupling of the engine from the driven wheels allows the use of high-speed engines, where it is difficult to directly propel the wheels through a mechanical link, such as gas turbines or power plants that have slow dynamic responses (e.g., Stirling engine, etc.).

- ✓ Because electric motors have a torque-speed profile that is very close to the ideal for traction. The drivetrain may not need multigear transmission.

- ✓ Therefore, the structure of the drive train can be greatly simplified and is of less cost.

  1. Furthermore, two motors can be used, each powering a single wheel, and the mechanical differential can be removed. Such an arrangement also has the following advantages of decoupling the speeds of two wheels, a similar function of a mechanical differential, and an additional function of anti slip similar to the conventional traction control.

  2. Furthermore, four in-the-wheel motors can be used, each one driving a wheel. In such a configuration, the speed and torque of each wheel can be independently controlled. Consequently, the drivability of the vehicle can be significantly enhanced. This is very important for off-road vehicles which usually operate on difficult terrain, such as ice, snow, and soft ground.

- ✓ The control strategy of the drive train may be simple, compared to other configurations, because of its fully mechanical decoupling between the engine and wheels.

3. DESIGN USP'S AND KEY FEATURES

3.1 Solar Hybrid will have compact dimensions

One of the major design considerations while development of the car was the inescapable fact that with ever expanding cities, traffic snarls have become an inevitable fact of daily life**.** The important fact is that most vehicle owners commute alone everyday to work which leads to unnecessary bulk and fuel consumption. To tackle this problem, the solar hybrid vehicle is compact greatly enhancing urban maneuvering.

3.2 Safety was a high priority

This was achieved with the inclusion of Formula 1 derived materials philosophy and technology coupled with chassis frame design ('Direct Load Path) gives an immensely strong structure ('safety cell') both in 'end' and 'side' impact scenarios. This is also designed to meet the cost target of high volume production.

3.3 Commercialization of the product

To make the solar hybrid vehicle more accessible, costs would be low. This will be achieved by developing the vehicle on an existing platform which is currently in mass commercial production. thus ensuring that the solar electric hybrid vehicle can be converted from 'Project' to a 'Product' in a short span of time. Standardizing certain parts like steering, suspension etc. will ensure that the same assembly line can be utilised.

4. STRUCTURAL DESIGNING

4.1 Basic requirements of stiffness and strength

The chassis needed to be strong enough to support the weight of batteries, genset, motor and passengers. The purpose of the structure is to maintain the shape of the vehicle and to support the various loads applied to it.

The structure usually accounts for a large proportion of the development and manufacturing cost in a new vehicle programme, and many different structural concepts are available to the designer. It is essential that the best one is chosen to ensure acceptable structural performance within other design constraints such as cost, volume and method of production, product application, etc. Assessments of the performance of a vehicle structure are related to its strength and stiffness. A design aim is to achieve sufficient levels of these with as little mass as possible.

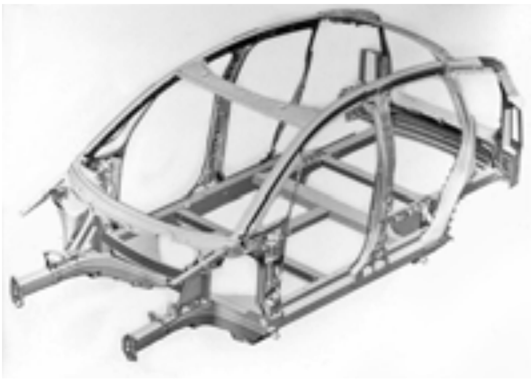

Fig 4.1: Perimeter space frame chassis

4.2 Perimeter space frame or 'birdcage' frame

Modern structure is the perimeter or 'birdcage 'frame. A typical example is the Audi A2 aluminium vehicle. In this type of structure, relatively small section tubular members are built into stiff jointed 'ring-beam' bays, welded together at joints or 'nodes'. For this, the edge members of each ring frame, and especially the corners, must be stiff locally in bending. This choice of construction method is usually dictated by production requirements. In the case of the A2, the various beam sections are of extruded or cast aluminium (with some additional members of pressed sheet), and so they must be assembled into this structural concept using welded ‘nodes’ or joints. The individual open-bay ring frame is not a very weight efficient shear structure. If the (very high) shears stiffness of the skin panels is incorporated into this type of body, it now becomes an ‘integral’ structure (see above), and a considerable increase in torsional rigidity is usually observed, depending on the stiffness of the attachment.

4.3 Punt or platform structure

Other modern car chassis types include the ‘punt structure’. This is usually of sheet metal construction, in which the floor members (rocker, cross-members etc.) are of large closed section, with good joints between members. It is thus a grillage structure of members with high torsion and bending properties locally. In many cases (but not all), the upper body is treated as structurally insignificant. The punt structure is often used for low production volume vehicles, for which different body styles or rapid model changes are required. This approach is often also used to create cabriolet or convertible versions of mass produced integral sedan car structures.

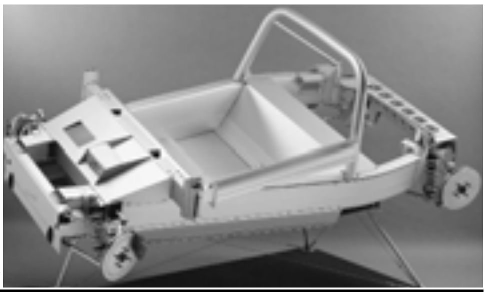

Fig 4.2: Punt chassis of Lotus

4.4 Solar Electric Hybrid Vehicle structure

From the discussion stated above it can be concluded that no one chassis type can provide all the requirements of solar electric hybrid vehicle. Therefore, the structure would include of custom designed punt platform incorporated with a spaceframe that will provide torsional rigidity. This setup would ensure superior vehicle dynamics and at the same time be lightweight. To keep the cost low this structure can be developed on an existing unibody or monocoque structure ensuring that few modifications are required for production.

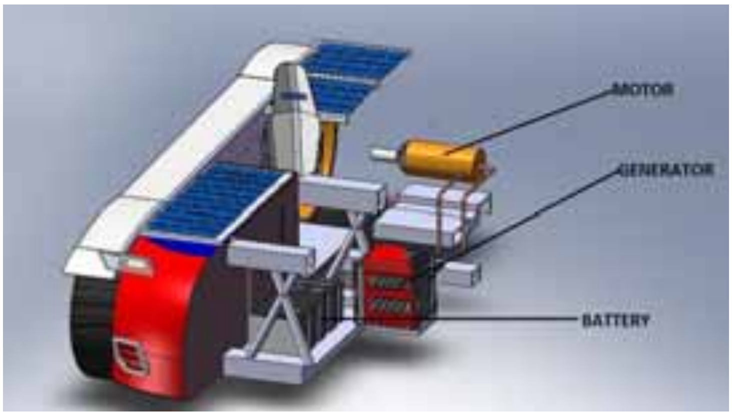

Fig 4.3: Punt platform incorporated with spaceframe

4.5 Solar Electric Hybrid Vehicle Body Design

Fig 4.4: **Compact body for easy maneuvering and parking (Note: Detailed working drawing can be provided on request)**

Aerodynamics forces interact with the vehicle causing drag, lift (or download, lateral forces, moments in roll, pitch and yaw, and noise .These impact fuel economy, handling and NVH. The aerodynamic forces produced on a vehicle arise from two sources- form (or passage) drag and viscous friction. Drag is the largest and most important aerodynamic force encountered by passenger cars at normal speeds.

The drag force is most easily understood if it is broken down into five constituent elements. The most significant of the five in relation to road vehicles is the form drag or pressure drag which is the component that is most closely identified with the external shape of the vehicle. As a vehicle moves forward the motion of the air around it gives rise to pressures that vary over the entire body surface. If a small element of the surface area is considered then the force component acting along the axis of the car, the drag force depends upon the magnitude of the pressure, the area of the element upon which it acts and the inclination of that surface element. Thus it is possible for two different designs, each having a similar frontal area, to have very different values of form drag. As air flows across the surface of the car frictional forces are generated giving rise to the second drag component which is usually referred to as surface drag or skin friction drag. If the viscosity of air is considered to be almost constant, the frictional forces at any point on the body surface depend upon the shear stresses generated in the boundary layer. The boundary layer is that layer of fluid close to the surface in which the air velocity changes from zero at the surface (relative to the vehicle) to its local maximum some distance from the surface. That maximum itself changes over the vehicle surface and it is directly related to the local pressure. Both the local velocity and the thickness and character of the boundary layer depend largely upon the size, shape and velocity of the vehicle.

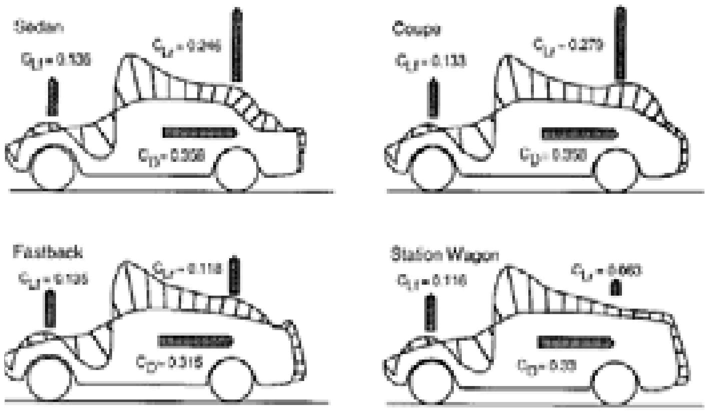

Fig 4.6: Various Vehicle Body Styles

A consequence of the constraints imposed by realistic passenger space and mechanical design requirements is the creation of a profile which in most situations is found to generate a force with a vertical component. That lift, whether positive (upwards) or negative, induces changes in the character of the flow which themselves create an induced drag force. Practical requirements are also largely responsible for the creation of another drag source which is commonly referred to as excrescence drag. This is a consequence of all those components that disturb the otherwise smooth surface of the vehicle and which generate energy absorbing eddies and turbulence. Obvious contributors include the wheels and wheel arches, wing mirrors, door handles, rain gutters and windscreen wiper blades but hidden features such as the exhaust system are also major drag sources.

Although some of these features individually create only small drag forces, their summative effect can be to increase the overall drag by as much as 50%. Interactions between the main flow and the flows about external devices such as door mirrors can further add to the drag. This source is usually called interference drag. The last of the major influences upon vehicle drag is that arising from the cooling of the engine, the cooling of other mechanical components such as the brakes and from cabin ventilation flows. Together these internal drag sources may typically contribute in excess of 10% of the overall drag.

Optimisation of vehicle bodies results in:

- Considerable improvement in efficiency
- Improvement of comfort characteristics and
- More favourable driving characteristics of ground vehicles.

5. TRANSMISSION AND DIFFERENTIAL

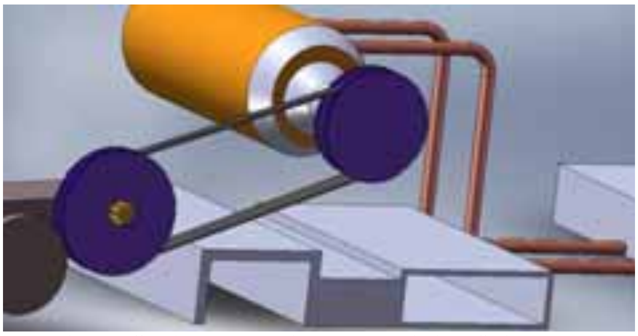

Fig 5.1: Continuously Variable Transmission (Solidworks)

Unlike traditional automatic transmissions, continuously variable transmissions don't have a gearbox with a set number of gears, which means they don't have interlocking toothed wheels. The most common type of CVT operates on an ingenious **pulley system** that allows an infinite variability between highest and lowest gears with no discrete steps or shifts. Most CVTs only have three basic components:

- A high-power metal or rubber belt
- A variable-input "driving" pulley
- An output "driven" pulley

CVTs also have various microprocessors and sensors, but the three components described above are the key elements that enable the technology to work. The variable-diameter pulleys are the heart of a CVT. Each pulley is made of two 20-degree cones facing each other. A belt rides in the groove between the two cones. V-belts are preferred if the belt is made of rubber. V-belts get their name from the fact that the belts bear a V-shaped cross section, which increases the frictional grip of the belt.

When the two cones of the pulley are far apart (when the diameter increases), the belt rides lower in the groove, and the radius of the belt loop going around the pulley gets smaller. When the cones are close together (when the diameter decreases), the belt rides higher in the groove, and the radius of the belt loop going around the pulley gets larger. CVTs may use hydraulic pressure, centrifugal force or spring tension to create the force necessary to adjust the pulley halves.

Variable-diameter pulleys must always come in pairs. One of the pulleys, known as the drive pulley (or driving pulley), is connected to the crankshaft of the engine. The driving pulley is also called the input pulley because it's where the energy from the engine enters the transmission. The second pulley is called the driven pulley because the first pulley is turning it. As an output pulley, the driven pulley transfers energy to the driveshaft.

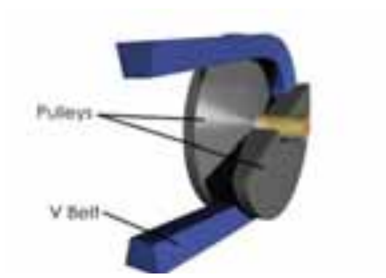

Fig 5.2: Pulley System

When one pulley increases its radius, the other decreases its radius to keep the belt tight. As the two pulleys change their radii relative to one another, they create an infinite number of gear ratios -- from low to high and everything in between. For example, when the pitch radius is small on the driving pulley and large on the driven pulley, then the rotational speed of the driven pulley decreases, resulting in a lower "gear."

When the pitch radius is large on the driving pulley and small on the driven pulley, then the rotational speed of the driven pulley increases, resulting in a higher “gear.” Thus, in theory, a CVT has an infinite number of "gears" that it can run through at any time, at any engine or vehicle speed.

The simplicity and stepless nature of CVTs make them an ideal transmission for a variety of machines and devices, not just cars. CVTs have been used for years in power tools and drill presses.

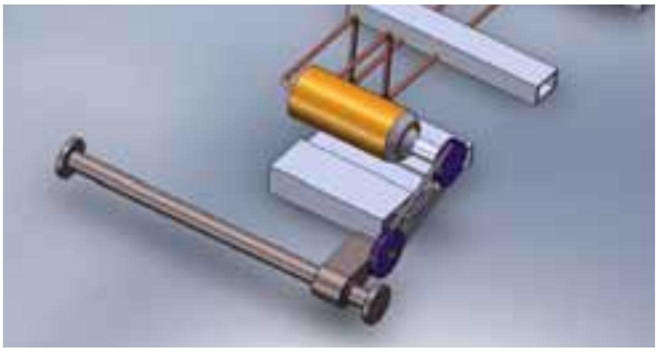

Fig 5.3: Solidworks Model of Drivetrain

The differential is a device that splits the engine torque two ways, allowing each output to spin at a different speed.

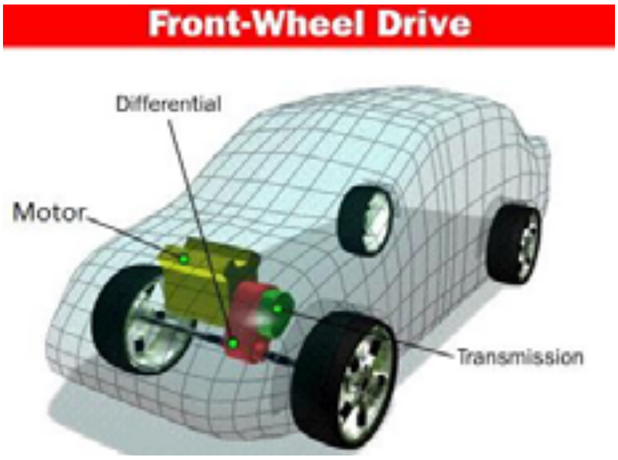

Fig 5.4: Front Wheel Drive

A vehicle's wheels rotate at different speeds, mainly when turning corners. The differential is designed to drive a pair of wheels while allowing them to rotate at different speeds. In vehicles without a differential, such as karts, both driving wheels are forced to rotate at the same speed, usually on a common axle driven by a simple chain-drive mechanism. When cornering, the inner wheel needs to travel a shorter distance than the outer wheel, so with no differential, the result is the inner wheel spinning and/or the outer wheel dragging, and this results in difficult and unpredictable handling, damage to tires and roads, and strain on (or possible failure of) the entire drivetrain.

6. TECHNICAL SPECIFICATIONS

Tab 6.1: Electrical components description

S. No	Component	Description	Quantity
1.	Motor	Hub Brushless DC Motor 48V, peak 20kW (Model: HPM-10kW) from Golden Motors, China	1
2.	Motor controller	HPC500A, 48V , 300amp peak from Golden Motors, China (Regenerative Braking included)	1
3.	Maximum power point tracker	MPPT Solar Charge controllers From AERL, Model : SMV24	1
4.	Batteries	48V, 100Ah with Battery Management System (BMS) and charger	1
5.	Solar Panels	Silicon solar cell panels of 14% efficiency (32W each)	5
6.	Genset	Honda Portable Genset (5.5kVA, 16.5 Ltrs. capacity)	1
7.	Instrument Panel (Monitoring System)	Complete Instrument Panel with Speedo, 48V and 12V gauges and all warning lights plus Additional Motor Temperature Gauge & Charge Warning Light.	1
8.	LabView 2010 Multisim 2010	Electrical Simulation Software Electrical circuit Designing Software	1

Tab 6.2: Mechanical components description

S. No	Component	Description	Quantity
1.	Brakes	Front: Hydraulic Disc Brakes Rear: Internally Expanding Drum Brakes	1
2.	Steering	Rack and Pinion	1
3.	Suspension	Front: McPherson Strut Rear: Torsion-bar rear suspension	2
4.	Transmission	Continuously Variable Transmission (CVT)	-
5.	Chassis	Custom designed punt platform incorporated with a spaceframe	-
6.	Solidworks 2009	3D Desiging Software	1

6.3 PRODUCT SPECIFICATIONS

6.3.1 BATTERY PACK

Tab 6.3.1: Battery specification

Parameter	Value
Module capacity	48V, 100AH
Type	Lithium Iron Phosphate
Energy	4.8 kWh
Maximum discharge current	240 Amp
Charging cycle life	3000 cycles @ 70% DOD
Module weight	42 kg (approx.)

Battery pack is non-toxic, non-contaminating, and compact in size and light in weight. It can be used for all high power output applications and can be used under extreme temperature. It's extremely safe as well (no explosion, no fire under collision, over charged or short circuit).

Why Lithium iron phosphate batteries?

- Faster charging
- Large overcharge tolerance and safer performance.
- Self balance.
- Simplified BMS system due to self balance and large overcharge tolerance features.
- Longer cycle life. (3000 cycles @ 70% DOD)
- High temperature performance.

Fig 6.1: Solidworks Model of Genset

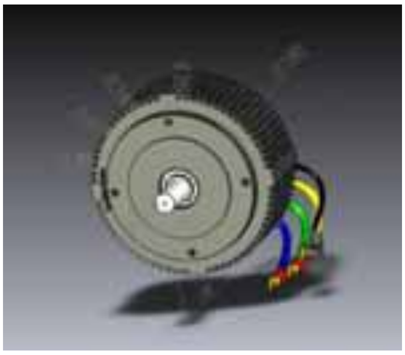

Fig 6.2: Solidworks Model of Motor

6.3.2 GENSET (Portable diesel powered GENSET)

Tab 6.3.2: Battery specification

Parameter	**Specifications**
Engine	Honda GX390
Displacement	389cc
AC Output	120/240V 6500W max. (54.1/27.1A) 5500W rated (45.8/22.9A)
Receptacles	20A 125V Duplex, 30A 125V Locking Plug, 30A 125/250V Locking Plug
Engine HP	13 HP
Starting System	Recoil, electric
Fuel Tank Capacity	16.5 (ltrs)
Run Time per Tankful	14.0 hrs.
Dimensions (L x W x H)	33.5" x 26.4" x 27.5"
Noise Level	60 dB @ rated load 52 dB @ 1/4 load
Dry Weight	260 lbs.

- Fuel consumption of GENSET is 0.26 gal/hr if it is continuously run. If we the vehicle is able to travel 30-40 miles then the fuel efficiency of the vehicle is 115 MPG! (Toyota prius has an average of 72 MPG)
- Toyota Prius emits 101 gm/km of CO2 whereas GENSET emits 1/10 th of that value.
- Flexifuel models are also available so environment friendly fuels like biodiesel or ethanol can also be used.

6.3.3 MOTOR (High Power Brushless DC Motor)

Tab 6.3.3: Motor specification

Parameter	Value
Voltage	48V
Rated Power	10kW (20kW peak)
Efficiency	88%
Speed	2000-6000 rpm (customizable)
Weight	11Kgs
Length (height)	126mm
Diameter	206mm

The high power BLDC motor is compact in design, water resistant and is having a stainless steel shaft. It's equipped with self-cooling fan as well.

6.3.4 SOLAR ARRAY

Panels will be made from multicrystalline Silicon solar cells of rated efficiency 16.66% and the panels thus formed will be of efficiency of about 14%. Panels will be placed over an area of 4.2 square meters on the vehicle. The estimated output we will get from the panels placed over the vehicle on a sunny day will vary between 150-200W.

7. REFERENCES

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