

# Study on Powertrain Circuit and Subsystems of Solar Electric Hybrid Bus

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**ABSTRACT:** This paper focuses on the study of hybrid powertrain circuit and important subsystems of a solar electric hybrid bus to reduce the manufacturing cost, operating cost and emissions. The powertrain circuit of solar hybrid bus has been designed and analysed comprehending the addition of solar panels in the powertrain and the increased weight due to the same. Use of hybrid technology reduces the emissions up to 30-35% but with solar energy, emissions can be reduced up to 55%. Comparison between petrol, diesel and CNG is done to justify the use of CNG as the engine fuel. Comparisons are also carried out between Monocrystalline and Polycrystalline solar panels and the one with the more efficiency and power to weight ratio is selected i.e. Monocrystalline solar panels. Monocrystalline panels produce 120-180 Watt per meter square against 50-80 Watt per meter square of power produced in case of Polycrystalline panels. Ambiguity in the use of either Ni-MH or Li-ion battery in hybrid buses is resolved. Selection of electric motor with 350 hp, 1000 Nm torque and 3450 rpm yields  $0.8 \text{ m/s}^2$  maximum acceleration, 74.74 km/hr maximum velocity and reduction gearbox of gear ratio between 2:1 to 3:1.

**KEYWORDS:** Solar hybrid city bus, CNG, Powertrain, Solar, Transport.

## I. INTRODUCTION

With the world running out of fuel, other forms of energy should be significantly considered to propel a vehicle. Electric vehicle industry is growing rapidly because of low emissions and high energy saving. Hybrid technology has also cemented its place in the automobile industry since electric alone cannot deliver required performance. Countries are moving towards hybrids for cars, buses etc. even in India hybrid buses have been rolled out in Mumbai city but one thing that hasn't crossed anyone's mind is the utilisation of solar energy to charge batteries that will ultimately power electric motor. The amount of space a bus offers for the installation of solar panels is enough to generate 51.84 - 77.76 kWh per day considering 9 hours of sunlight exposure. Since it is a hybrid vehicle so let's talk about fuel to be used in IC Engines. Automotive companies offer diesel over petrol and CNG even though CNG is way cheaper and easily available. India being the 7th largest reserve of CNG in the world should consider CNG instead of diesel for the propulsion of hybrid electric vehicles. Use of hybrid circuits in city buses reduces 30-35 % emissions but with solar energy, it will reduce up to 50-55 %. In this paper, the structure of the powertrain system of solar hybrid city bus will be discussed. Justification of important subsystems will be provided. Later on powertrain calculations based on horsepower and torque from the electric motor will be elaborated.

## II. RELATED WORK

Researchers have proposed hybrid electric buses incorporating the use of series and parallel circuit according to their convenience with use of permanent magnet motor. Focus is laid on reducing the emissions by charging the batteries with either plug in option or relying on regenerative braking which will keep the electric motor running for a longer duration. Most of the buses have adopted parallel circuit thereby leading to the use of power split device which is a planetary gear set mechanically connecting planetary carrier to the engine and ring gear to the electric motor.

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Fuel to be used was also a topic of parlance where usage of either diesel, petrol or CNG depends mainly upon the availability and price in that region, keeping emissions in the hindsight.

Study on electric vehicles, running on solar energy, for different applications was conducted where installation, maintenance work and total cost was area of research. Selection of solar panels caused a great deal of trouble among the researchers where ultimately Monocrystalline solar panels sidelined Polycrystalline solar panels.

Researchers also compared Li-ion and Ni-MH battery, where in some cases, use of Ni-MH was preferred because it can be used for a longer period under proper maintenance whereas others preferred Li-ion as it has higher power to weight ratio and it does not show any sign of so called memory effect, associated with Ni-MH battery.

## III. HYBRID CIRCUIT SELECTION

Powertrain circuit of a hybrid vehicle can be divided into three types i.e. Series hybrid (figure a), Parallel hybrid (figure b) and Combined hybrid (figure c) (series and parallel both along with power split device).

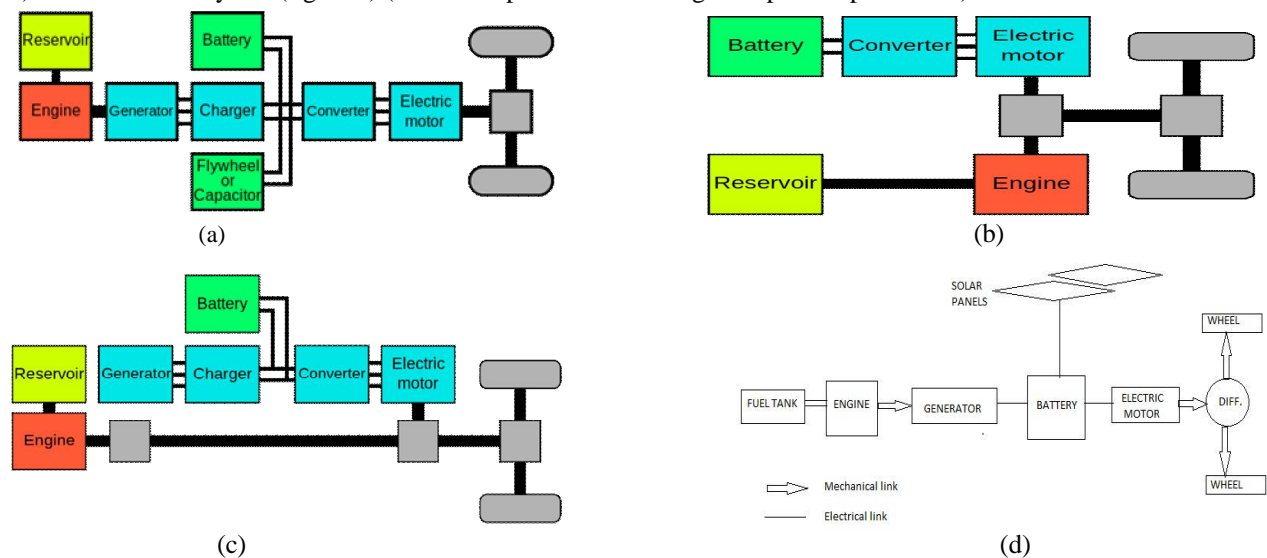
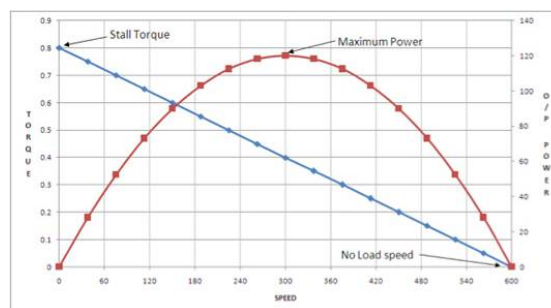


Figure (d) shows the powertrain circuit of solar hybrid electric bus.

There are several advantages of using series circuit over parallel and combined circuit.

In series circuit, electric motor can be directly attached to the wheels or to a differential with a reduction gear box since the torque vs. rpm curve of an electric motor closely resembles that of an ideal required by a vehicle. The curve is shown in graph (e).



(e)

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Since the IC engine has no direct mechanical link with the wheels of the bus and its sole purpose is to run the generator so downsizing of engine is possible and hence decreasing the weight of the bus which was more than required because of the installed solar panels and batteries.

Series circuit allows the vehicle to be low floor in contrast to parallel circuit hybrid vehicles where a lot more space is required for installation. Another major advantage of series hybrid vehicle is that the IC engine is mostly running at optimal speed and torque or in other words, within a narrow rpm range which increases engine efficiency and decreases emission. Moreover, when batteries are fully charged, engine can be turned off thereby trimming down the fuel consumption.

In figure 1 you can see that when the batteries are fully charged the Engine can be turned off and when batteries are discharged, motor will run with the help of generator meanwhile battery will be recharged with the help of solar energy, regenerative braking and excess power from the generator.

Another characteristic of series circuit is that when high power is required by motor, it utilises energy from both motor and batteries, which is an added advantage not present in parallel circuit hybrid vehicles.

#### IV. ENGINE FUEL SELECTION

What augers well for CNG is that there is no lack of availability of fuel in India. India has the 7th largest reserves of CNG in the world.

When it comes to emissions, CNG has 20% lower emissions of CO<sub>2</sub> than petrol but a slightly higher than diesel.

One big factor against CNG as an automotive fuel was used to be the lack of safety and power loss that drastically reduced the pleasure of driving. The first part of the problem however has been addressed to some extent with companies introducing gas port injection technology. The newer technology has also reduced the power loss associated CNG and these cars now have pick up and drive similar to that of petrol car.

Comparison of prices (Rs. /lt.) in India.

Petrol: 65.6

Diesel: 53.9

CNG: 38.15

Although more CNG is consumed than petrol measured for a particular distance but still the overall expenditure will be significantly less as compared to that of petrol or diesel.

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#### V. SOLAR PANEL SELECTION

Solar panel refers to a panel designed to absorb the sun's rays as a source of energy for generating electricity or heating. Solar panels can be broadly categorised as

Monocrystalline (Or Crystalline PV glass)

Polycrystalline (Or Silicon wafer PV glass)  
(PV stands for Photo Voltaic)

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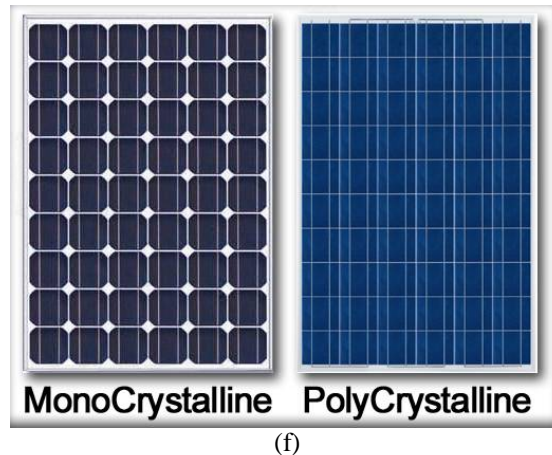


Figure (f) shows the visual difference between Monocrystalline and Polycrystalline solar panels.

Monocrystalline panels are the most efficient types of solar panels. In other words, when sunlight hits these panels, most of it turns into electricity than the other types below. As a result of their high silicon content, they're also more expensive, but you need fewer of them for your requirements.

On the other hand, Polycrystalline panels have lower silicon levels than Monocrystalline panels. In general, that makes them less expensive to produce, but they're also slightly less efficient.

According to a rough estimate, Monocrystalline panels produce 120-180 Watt per meter square against 50-80 Watt per meter square of power produced in case of Polycrystalline panels.

For the purpose of Solar Hybrid bus for intercity and within a city commute, power to weight ratio has a very important role to play. Monocrystalline panels are producing more power for less area of solar panels, meaning lesser weight of panels (Overhead load). Thus they have higher power to weight ratio as compared to Polycrystalline panels.

Roof area of an average sized bus is around 31-meter square for mini buses and 48-meter square for large buses. Assuming 9 hours of sunlight exposure (8 AM to 5 PM), we get 33.48-50.22 kWh per day for mini buses and 51.84-77.76 kWh per day for large buses, using monocrystalline panels.

## VI. SELECTION OF BATTERY

The following are the points why Li-ion battery is preferred over Ni-MH battery: -

- Lower self-discharge rate.
- Weight and size of Li-ion battery is less than that of Ni-MH which facilitates in overall abatement of weight.
- A single cell of Li-ion battery has output voltage up to 3.7V whereas in case of Ni-MH it is only 1.2 V.
- Recharge time of Li-ion varies from 1-3 hours whereas for Ni-MH it varies from 10-12 hours.
- Can tolerate low temperature as compared to Ni-MH battery.
- Ni-MH suffers from "Memory effect" which is not an issue in Li-ion battery.
- Specific energy of Li-ion varies from 80-130 W-h/kg whereas for Ni-MH it varies from 60-80 W-h/kg.

Tabular Comparison

Battery	Ni-MH	Li-ion
Specific Power (W / kg)	200-300	200-300
Specific Energy (W-h / kg)	60-80	80-130
Efficiency (%)	70	>95

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In the above table we can see that, although the Specific power of Li-ion and Ni-MH are same but when we compare specific energy, Li-ion finishes above Ni-MH. Even in case of efficiency, Li-ion edges past Ni-MH battery.

## VII. POWERTRAIN CALCULATION

To propel a city bus, electric motor should have following minimum requirement:

Power =  $P = 350\text{HP}$   
Torque =  $T_m = 1000\text{ N-m}$   
RPM =  $N_m = 3450$

Let:

Radius of bus wheels =  $r_w = 0.7\text{m}$   
Rolling radius of wheels =  $R_w = 0.69\text{m}$   
Axle ratio =  $\eta = 4 : 1$   
Reduction gear box ratio =  $\eta_r = 3 : 1$   
Kerb mass of bus =  $M = 12000\text{ kg}$   
Overall mass of bus =  $M = 19000\text{ kg}$   
Rolling resistance coefficient =  $k = 0.011$  (Concrete road)

So for maximum acceleration:

Torque on wheels =  $T_w = T_m \times \eta \times \eta_r$   
 $= 1000 \times 4 \times 3$   
 $= 12000\text{ Nm}$   
Consequently, force on wheels =  $F_w = T_w / R_w$   
 $= 12000 / 0.69$   
 $= 17391.30\text{ N}$   
Rolling Resistance =  $R_r = Mg \times k$   
 $= 19000 \times 9.81 \times 0.011$   
 $= 2050.29\text{ N}$   
Overall tractive force on wheels =  $F_T = F_w - R_r$   
 $= 17391.30 - 2050.29$   
 $= 15341.01\text{ N}$   
Acceleration of bus =  $F_T / M$   
 $= 15341.01 / 19000$   
 $= 0.81\text{ m/s}^2$

For maximum velocity:

Bus wheel rpm =  $N_w = N_m / (\eta \times \eta_r)$   
 $= 3450 / (3 \times 4)$   
 $= 287.5$   
Maximum speed of bus =  $N_w \times (2\pi \times R_w / 60)$   
 $= 287.5 \times 2\pi \times 0.69 / 60$   
 $= 20.76\text{ m/s}$   
 $= 74.75\text{ km/hr}$

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## VIII. REDUCTION GEARBOX SELECTION

The maximum reduction ratio for the gear box should be 3:1 for proper performance of the powertrain and it should not be lower than 2:1.

Calculations above are based on the gear ratio of 3:1 which is sufficient for a city bus.

## IX. CONCLUSION

Reduction in manufacturing cost, operating cost and emissions are the stand out criteria for the fabrication of solar hybrid city bus where engine is powered by Compressed natural gas (CNG).

Adoption of series hybrid circuit aids in following objectives i.e. decrease in emissions and manufacturing cost as compared to parallel and combined.

Use of CNG as an engine fuel reduces the operating cost considerably and also adheres to the current pollution control.

Installation of solar panels decreases the recharging time of the batteries. Although it leads to increase in overall weight of the vehicle but this drawback is tackled by use of series hybrid circuit (Downsized engine, single gear reduction) and use of light weight batteries (Li-ion).

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