ELECTRIFICATION OF ROAD TRANSPORTATION USING GROUND LEVEL POWER SUPPLY (Policy brief)

Abstract:

In this report a new technology is discussed about which has multitude of advantages over existing road transportation technologies that make it better than the present technology in numerous ways. Later a policy will be formulated to support the new technology and to ensure that full benefit of the technology is utilized.

By electrification of roads using ground level power supply we talk about the scenario in which all major freeways and roads are laid with **Ground-level power supply**, also known as **surface current collection** and **Alimentation par Sol** (**APS**) which is a modern method of third-rail electrical pick-up for street trams which was invented for the Bordeaux tramway, which was constructed from 2000 and opened in 2003. This allows the road running cars to use electricity directly from the source rail and eliminates the use of gasoline for regular running and may even eliminate the engine all together. The cars will be equipped with a small on-board battery pack that can be used while the car has to exit the main roads and have to hit the parking lots and other smaller roads that has not been laid with the new technology. This technology ensures lower green house gas emission in the cities, use of high efficiency electric motors. The cars will also be wired together so that they know the exact location of the other car so that crashes can be avoided and hence cars can be designed to be lighter.

Existing technologies:

Today 95% of transportation sector in US relies on petroleum in the form of gasoline or diesel or other. Reasons why petroleum is the most popular source of energy for transportation is as follows:

1. Very high energy/power density of gasoline & diesel compared to other technologies like batteries, compressed air, hydrogen (unless it is liquefied hydrogen)
2. Very mature technology which has been there for decades
3. Steady supply of fuel though with fluctuating fuel prices

There are a lot of disadvantages associated with the use of petroleum as a fuel and the most important ones are

1. Tail pipe emissions like CO2, NOx, SOx, CO, HC, Soot which are poisonous or a kind of green house gas resulting in global warming.
2. Depletion of non-renewable fossil fuel resources

The former reason mentioned is a greater threat today and needs immediate attention.

Proposed new technology:

The proposed new technology eliminates the use of petroleum on road running vehicles (off-road vehicles may still use petroleum as primary source of power). The technology calls for an infrastructure development on a large scale. All major roads are to be laid with ground level power supply which is also known as surface current collection or Alimentation par sol (APS) which is a modern method of third-rail electrical pick up for street trams. This system was constructed in 2000 and opened in 2003 for the Bordeaux tramway. With the new infrastructure in place the road running vehicles will be able to source power directly from the grid and the high efficiency electric motor on-board of the vehicle ensures zero emissions at the point of use (though emissions exist to an extent at the point of source).

The vehicles will be equipped with a small on-board battery pack that can be used while the car has to exit the major roads and have to hit the parking lots and other smaller roads that has not been laid with the new technology. Li-ion batteries will be the best choice since they have very good energy and power densities and high battery life. The size of the battery pack can be decided based on the distance one this he has to travel to hit the major roads. This can be customized as per customer requirements. Regenerative braking can be used to recover braking energy that would be otherwise lost as friction and heat. The battery can be kept at a State Of Charge (SOC) of 0.9 so that the remaining 10% can be kept available for regenerative braking.

Working of APS: APS uses a third rail placed between the running rails, divided electrically into eight-metre segments with three metre neutral sections between. Each vehicle will have two power collection skates, next to which are antennas that send radio signals to energize the power rail segments as the vehicle passes over them. At any one time no more than two consecutive segments under the vehicle should actually be live.

A section of APS track showing the neutral sections at the end of the powered segments plus one of the insulating joint boxes which mechanically and electrically join the APS rail segments

The infrastructure is about 300% more expensive than overhead wires but more aesthetically pleasing and reliable during bad weather. The cost can come down a lot when implemented in a large scale.

Advantages of switching to new technology from old are as follows:

1. The major benefit of going for the new system will be reduction of emission. The new system will emit zero emissions on road and the emissions from the plant are easier to handle with dedicated scrubbers and SCR and carbon sequestration techniques.
2. The next major benefit will be that USA will be free from dependence on oil imports and the fluctuating oil prices.
3. Power generation can be done more efficiently and renewable methods of power production can be employed.
4. High efficiency of electric motor ensures an improvement in overall system efficiency. This can offset the transmission losses associated with the electrical power distribution system which is normally very high.
5. Low maintenance due to fewer number of parts compared to an engine
6. High power to weight ratio of electric motor makes the vehicle lighter and hence ensures better acceleration and lower power consumption.
7. Electric motors can be overloaded for a short period of time and this usually happens during hill climbing etc. This ensures that a smaller motor is necessary for the same performance requirement.
8. Power to run the accessories can be directly tapped from the source grid instead of using the less efficient way of converting fuel into power and then power into electricity as done usually.
9. Regenerative braking can capture part of the braking energy that would be otherwise lost.
10. Lower NVH ensuring better comfort.
11. More room for passengers as the huge engine is replaced by a small electric motor.
12. No refueling to be done and lesser fuel price fluctuations as we do not depend on oil imports.

Impact on emissions:

As said earlier the major advantage is the lower emissions especially in cities. Emissions will now be concentrated at the electric power plants that run on coal, petroleum products, natural gas etc. But with the use of advanced technologies like SCR, scrubbers and carbon capture and sequestration techniques

this can be minimized to a great extent. Extracted exhaust gases can either be used productively or disposed safely and effectively.

Other important points to be noted:

Unlike the track-side third rail used by most metro trains and some main-line railways, APS does not pose a danger to people or animals, and so can be used in pedestrian areas and city streets.

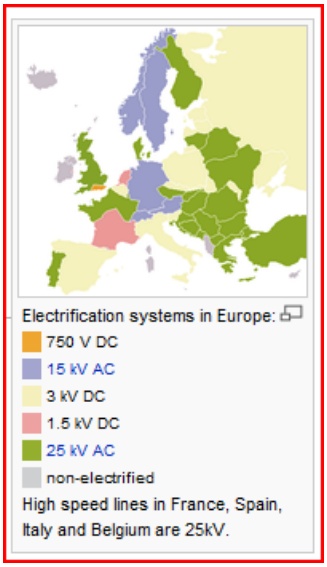
Vehicles can be made lighter as the chances of an accident is low with the new vehicle to vehicle communication system, thus giving better acceleration and lower power consumption.

Specially designed low rolling resistance tires can reduce power requirements.

Technical details:

1. Power supply options:

There are a variety of ways of powering the grid; a few of the most commonly used methods are as follows:



1. DC system (600V, 750V, 1500V-overhead, 3000V-overhead)

   DC carry 41% more power than AC but peak voltages limited so thicker conductors needed.

2. AC system (single phase- 15 kV 16⅔ Hz, 11 kV 25 Hz, 12.5 kV 25 Hz)

3. AC system multiphase

Proposed method: The best power supply option for our application will be 750V DC as this will call for a small lighter electric motor in the vehicle since it is DC.

2. Electric motor options:

1. Permanent magnet DC motors

2. Field excited DC motors

3. Field excited AC induction motors (single or multi phase)

Proposed motor: The motor that could be easily adapted for our application seems to be a permanent magnet DC motor due to high efficiency, low weight.

The power rating of the motor can be decided based on the size and power requirements of the vehicle. A 40Kw DC motor can replace a 70Kw Engine due to high initial torque and the capability to be used beyond the normal power ratings for short duration of time.

3. Battery options:

1. Lithium ion
2. Nickel metal hydride
3. Sealed lead acid

Proposed battery: Lithium ion battery will be the best suited in our application due to higher power and energy densities and long life.

4. Grid design options:

The grid has to be designed so that the power loss is minimum. The best way will be to transmit electricity at high voltages to an array of substations that receive power and supply the same to the rail at lower voltages. In this way we minimize the transmission losses associated with power transmission.

Recommended policy:

The recommended policy should ensure the following things:

1. ***Sufficient power supply when there is demand***
2. ***The price of power should remain constant without fluctuations***
3. ***The power produced is clean so that the benefits of green house gas reduction is prominent***
4. ***Make sure that the system is safe***
5. ***Bottlenecks and failures of the system should be predicted in advance and a fail proof design with alternate plans to be made***
6. ***Disaster planning to be made***
7. ***Allow users of engine run vehicles to convert to electric motor power with an incentive***

Now let us look at each of the important points to be considered and formulate a policy.

1. **Sufficient power supply when there is demand:**

The demand for electric motor run vehicles will grow rapidly due to the lower cost of running for these vehicles and lower maintenance. So the government should take steps to ensure enough clean power is available on demand at a low price. Therefore a huge expansion in power generation is necessary in the form of increasing capacity at existing plants and building new plants where ever necessary.

2. **The price of power should remain constant without fluctuations:**

The price of power has to be determined and it has to remain constant but the price can vary during different times of the day for example it may be the highest during the peak hours and may be lower during non peak hours and cheapest at night and weekends. A rough estimate of the cost of power is given below:

Peak hours (mornings and evenings): Cost = 1.5* current cost

Non peak hours (afternoons and late evenings): Cost = 1.1* current cost

Night and weekends: Cost = 0.9*current cost

The price of power should not be affected by the global demand of coal or petroleum and this should be ensured by increased coal mining and exploration and use of alternate power sources or fuels.

3. **The power produced is clean so that the benefits of green house gas reduction is prominent**:

The power production method has to be made cleaner by using advanced technologies or using renewable clean methods of power production. For example carbon capture, use of SCR and Scrubbers can make coal a clean method of power production.

Renewable clean methods like Solar, Wind, Geo-thermal, Hydro-electric etc, and use of bio fuels & nuclear power to be used where ever possible to generate power so that the carbon emission can be reduced and dependence on fossil fuels like coal and petroleum can be reduced.

4. **Make sure that the system is safe:**

Safety is critical for a project of this size. The amount of investment is huge and hence the system has to be made as safe as possible to people so that support of people is always available. People would never support an infrastructure that can put them in risk of life. The most important risk here is electrocution and

every measure to prevent that has to be taken into account. Fool proof systems have to be in place so that even if something fails, people are still safe.

5. **Bottlenecks and failures of the system should be predicted in advance and a fail proof design with alternate plans to be made:**

Systems can fail or perform bad at times and the important thing is to have alternate plans. For example the power to a substation may not be available and hence all the vehicles using that substation may not get enough power. Therefore the distribution of substations and the sizing of battery pack should be able to take care of this situation.

6. **Disaster planning:**

Disasters can occur and the range of the disaster can vary, so measures has to be put into place so that the rescue crew can reach the disaster areas in time and help people. Systems also should be in place to predict disasters so that they can be avoided.

7. **Device to prevent electrocution:**

Electrocution can be a big disaster can it can be avoided by instantly switching off the power if electrocution is sensed. This can be done if people carry a device that senses the current levels passing through them and when it goes over a limit, it can trigger the substation to switch off the power and earth it so that power stops flowing through the individual.

8. **Allow users of engine run vehicles to convert to electric motor power with an incentive:**

Even thought the running cost of electric motor run cars will be lower than gasoline or diesel fuel run vehicles, the cost involved in converting can be huge and government should take steps to help users of normal cars to convert to electric motor run vehicles with a price incentive. This will help in cleaning up the cities faster by reducing the number of gasoline run vehicles and hence will enable in reduction of emissions too.

Alternative technologies to reduce emissions and reduce dependence on petroleum:

Many alternate technologies exist that could help to reduce emissions and dependence on petroleum imports and the most important ones are:

1. **Plug in hybrid electric vehicles (PHEV)**

The use of plug in hybrid electrics can ensure lesser dependence on petroleum as most of the distance is covered using the electric mode alone and the engine is called for only in situations that absolutely require more power than what the motor could offer or when the battery's State of Charge (SOC) falls below a lower limit.

Disadvantages of PHEV:

1. The engine is not completely avoided
2. Cost of the vehicle is high as it has both the engine and the battery pack
3. The vehicle weight is usually more than the base engine vehicle due to the two power packs and due to the huge bank of batteries that has to be used.
4. The range in the electric mode is limited and it is sluggish in EV mode due to the underpowered electric motor.
5. Battery replacement is expensive

2. **Electric vehicles with range extender:**

These vehicles also have an engine but here the engine is called for only when the battery is discharged and the engine's role is usually to re-charge the battery and in a few designs the engine can actually power the vehicle. The engine is usually a low capacity engine that can work efficiently in steady state and re-charge the battery pack.

Disadvantages of EV:

1. This system uses a bigger battery pack and motor so is expensive and sluggish due to the increased weight.
2. The engine is not avoided and the energy conversion from fuel to power to electricity to re-charge the battery has a low overall efficiency
3. Battery replacements can be extremely expensive.

3. Hydrogen fuel cells:

Hydrogen economy looks very promising and fuel cells that operate at high efficiencies have been developed and tested already. The only problem still unsolved with this is the production and storage methods for hydrogen. Hydrogen can be produced through a variety of methods but almost every method looks unsuitable for a very large scale hydrogen production except reforming hydrogen from hydrogenated fuels.

Another huge drawback to hydrogen technology is hydrogen storage. Pressurized hydrogen or hydrogen in liquid stage is a possibility. Hydrogen can also be stored as hydrides or on carbon nanotubes but good energy density is achieved only when hydrogen is liquefied and this consumes lot of energy and requires a huge infrastructure change by itself.

4. Bio-fuels

Even though bio-fuels have emissions the carbon is cycled faster in the loop here. Bio-fuels can be produced from renewable sources like waste wood in the form of cellulosic bio-fuel like the cellulosic ethanol and this seems attractive as this can be produced in large volumes. The biodiesel produced from plant/vegetable/waste oil is also a good option. But the technology needs infrastructure development and emissions are not avoided but may be reduced.

Concluding remarks:

The proposed technology if installed with the proper supporting infrastructure and if the important points mentioned above are considered in policy deployment it can bring about a turnaround in road transportation and will be a milestone in emission reduction. Moreover USA will be energy sufficient and will no longer need to depend upon oil imports. The technology has great potential and hence will help in developing hundreds of thousands of new jobs and will come handy in a situation where economy is hit greatly and unemployment is at its peak.