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Converting automobiles into wind turbines: radiator fans in internal combustion engines and in electric vehicles as an untapped source of wind energy

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Abstract
Wind is a promising source of renewable energy. However, traditional wind farm installations face challenges such as downtime, land usage, grid connectivity, and environmental concerns. To overcome these challenges, we propose a novel approach that capitalizes on the ubiquitous presence of fossil fuel powered or electric vehicles. By retrofitting and installing radiator fans in the former and latter respectively, wind energy produced during motion can be harnessed and transformed into electrical energy. Our idea thus effectively converts all moving vehicles into wind turbines and is potentially infinitely scalable. Using a combination of mathematical models and empirical data, we demonstrate that a vehicle, fitted with three 16 inch, radiator fans (rated at 2 kW each) in front of the radiator, moving like pinwheels when the vehicle is in motion can generate and store 2.7 kW-h per day per vehicle in a 12 V, 230 AH deep cycle battery. This stored power, when uploaded at an 80% Depth Of Discharge, to the grid using Vehicle-to-Grid (V2G) or equivalent technology, is equivalent to 7.5% of the energy usage of a single family home per day. Our analysis finds that this approach could significantly offset residential energy needs; to the extent of 10% of the total power consumption by the US single family home stock, with positive contributions to carbon neutrality and energy balance. We propose a tax incentive and on-the-go reward system to incentivize participation, envisioning a future where vehicles serve both as transportation and as energy generation assets. To our knowledge, this approach has neither been proposed, nor been investigated before.

Keywords
Wind energy, Wind turbine, Renewable energy, Energy harvesting, Vehicle-to-Grid (V2G) technology, Energy efficiency, Radiator fan, Carbon neutrality, Internal combustion engine, Greenhouse gas emissions

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Introduction

Wind energy is harvested almost exclusively using wind turbines. Wind turbines need large rotor diameters to sweep more area, thus capturing more wind and producing more electricity. A turbine with longer blades can capture more of the available wind than shorter blades—even in areas with relatively less wind (1). This necessitates the building of large turbines on ‘wind farms’, vast areas of otherwise fertile land that often is left fallow since the income generated from harvesting the wind is greater than - or at least at par - with that generated by traditional farming (2). The former is also not as prone to the vagaries of (wind-independent) nature and/or dependent on a plethora of other factors as is the latter. Furthermore, these windswept vistas of land may or may not be located near the grid; thereby necessitating auxiliary power lines for connection (see below), adding to capital cost, maintenance, and power balancing requirements. Lastly, these installations frequently run afoul of environmental and wildlife conservation and preservation laws and/or policies (3).

Grid balancing refers to the situation where the electricity generated by the grid is equal to the electricity consumed from the grid. Overload in either direction can cause grid instability and interruption to power supply. Grid balancing has become less predictable with more renewable energy sources being installed into the grid. There have hence been situations where wind farm owners have been paid by the grid to not generate electricity. Therefore, wind farms need to be designed in locations where there is reasonable assurance that the energy they generate will be continuously usable by the grid. These locations may not be amenable to wind harvesting, thus necessitating farming in remote areas with long auxiliary power lines to connect to the grid. This implies that wind harvesting is more suited to at-location use in population sparse rural areas rather than to grid connectivity.

The wind turbine by itself is built on a solid foundation; is hence stationary and cannot move. It is hence solely dependent on the velocity of the wind flowing past it (how windy it is). Wind flow can be unpredictable; without adequate flow, the wind turbine generator has excess capacity that is not being used (4). Aside from the large capital cost of installation, wind turbines are projected to last the order of decades, and must be replaced (5).

These limitations of harvesting wind energy can be addressed if 1) A wind turbine can be designed that itself is mobile; i.e that can generate energy even under zero (stationary) wind conditions, 2) The turbine is therefore installed in a device or machine that is designed to be mobile, 3) Once the turbine has generated and stored enough energy, it must be capable of uploading the energy to the grid effortlessly and efficiently. 4) There must be a large enough number of these mobile machines so that the relatively small amount of energy generated and uploaded per machine is more than compensated for by their large number, such that the total wind harvested Watts of power are comparable to those harvested using the wind farm paradigm discussed above. 5) The owners of the wind turbines in these machines must be adequately compensated for their contribution to the energy uploaded to the grid.

The above requirements can be met if every vehicle can be converted into a wind harnessing machine. The most obvious method is to install a fan(s) of suitable diameter in the front of the vehicle so that the motion of the vehicle continuously moves the fan. If these fans were connected to generators and a battery, this would be a method to harness and store wind energy.

Materials

A 20 W, 24 V, DC generator (brand Walfront™, sourced from Amazon.com, Shenzhen Lanqui Technology Co., Shenzhen, China), was used to generate RPM-voltage and RPM-ampere plots. The housing for the gear assembly, (along with the gear assembly was dismantled, the crossed out pink lines in Figure 1) and the primary shaft was used to drive the generator without any gear trains. A Ryobi, D42, variable speed drill (Ryobi Tools, Anderson, SC, USA) was used to turn the generator shaft and a digital tachometer, 20713A (Neiko Tools, sourced from Amazon.com) was used to measure the RPM. A generic brand digital multimeter was used to measure the output voltage and current.

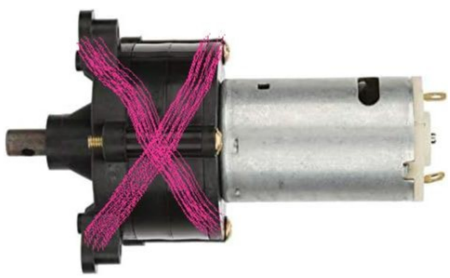

Figure 1. The gear train (pink cross) was removed from the generator and the primary shaft was used to measure the RPM, voltage and current.

Methods

In most internal combustion engine vehicles, the radiator fan is situated between the radiator and the engine block. It is powered on by a thermostat in the vehicle's cooling system, that senses when the coolant is too hot and turns on the fan using an electrical relay switch. The rotational energy of the fan forces ambient temperature air through the radiator vanes, thereby cooling the radiator fluid and consequently, cooling the engine (6). If another fan (or fans) were to be situated in front of the radiator (the so called 'pusher' fan), the velocity of the car could be used to continuously spin the fan(s) while the vehicle is in motion. The fan would be connected to a 2 kW generator that would feed into a 12 V, 230 AH battery (see below for calculations) used to store power to be uploaded to the grid. Pusher fans; though not common; are well known to automobile enthusiasts and frequently are DIY builds to provide extra cooling to the radiator.

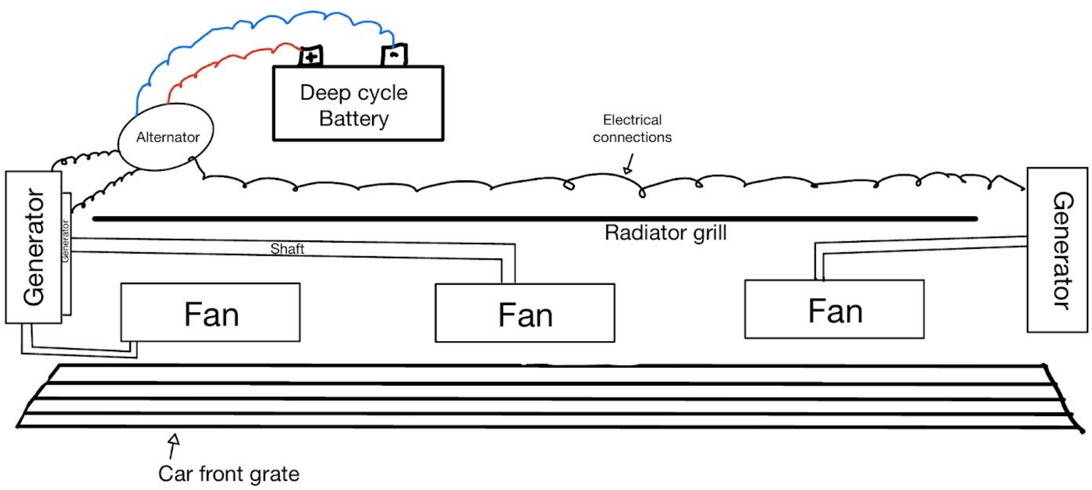

Figure 2. Schematic Top View of engine with three retrofitted 'pusher' fans. The fans are connected to the generators using bevel geared shafts that go underneath the housing. The generators feed into the car's alternator where the 220 V, AC is converted to 12 V DC, then fed into the deep cycle battery. The generators are separate from the fan due to the limited space between the radiator and the front grille.

Calculations

Two methods were used to calculate the energy output. In the first method (Table 1), we used the classical Newtonian equations to calculate the kinetic energy and Power. We used the equation for rotational kinetic energy, expressed in Joules (J). The equation for kinetic energy (KE) is

$$KE=0.5*(mass/s)*(wind\ velocity)^2 * 3600\ s$$

The equation to calculate the mass of the air moving through the wind turbine per second is given by $\rho*\pi*r^2*$(wind speed). Since, the mass rate (mass/s), rather than the mass of the air itself was calculable, the equation was multiplied by a factor of 3600 s to convert the dimensions to those of Energy (Joules). The kinetic energy was converted to Power by dividing by 3600. In addition, we used the Betz limit to calculate available power. The Betz limit is the theoretical maximum coefficient of power for any wind turbine; imposing a limit of 59.3% for transfer of the kinetic energy of the wind into the mechanical energy of turning a rotor.

In the second method (Table 2), we utilized the Horizontal Axis Wind Turbine (HAWT) equation to calculate the power. The equation is

$$P = 0.5 \times \rho \times A \times V^3$$

where ρ is the density of air (1.225 Kg/m^3), A is the windmill area perpendicular to the wind (0.1297 m^2) for a fan with a diameter of 16 inches and V is the velocity of the wind in m/s.

Results

Table 1. Calculation of power from a radiator fan wind turbine using classical Newtonian equations

Mph (Vehicle/wind speed)	m/s (Wind speed)	Blade linear tip speed (factor = 6) (m/s)	radians/s (Angular velocity)	Mass of air/s, (Kg/s)	Kinetic energy (KE) (J)	Power (W-h)	Power (W-h) using the Betz limit
70	31.29	187.74	909.15	4.97	8758707.4	2432.97	1435.45
60	26.82	160.92	791.93	4.26	5515687.5	1532.1	903.94
50	22.35	134.10	659.94	3.55	3191948.8	886.7	523.15
40	17.88	107.28	527.95	2.84	1634277.8	454.0	267.86
30	13.41	80.46	395.96	2.13	689460.9	191.5	113.00

Angular velocity (/s) = Tip speed/radius, Radiator fan diameter = 16 inches, weight = 2.7 Kg, ρ is the density of air (1.225 Kg/m^3), mass of air/s = ρ * volume/s, volume/s = $\pi * r^2 *$wind speed, Kinetic energy = 0.5*(mass of air/s)*(wind speed)^2 * 3600 s, W-h=KE/3600, The Betz limit is 59%

Table 2. Calculation of power from a radiator fan wind turbine using HAWT

Mph (wind speed)	RPM	m/s (wind speed)	Power (W-h)	Power (W-h) using the Betz limit	Total power per day (W-h) generated by a vehicle with three radiator fans driving one hour/day
70	1470.6	31.29	2433.68 (2055.8)	1435.87	4307.61
60	1260.5	26.82	1532.58 (1648.7)	904.22	2712.66
50	1050.4	22.35	886.91 (1051.0)	523.28	1569.84
40	840.3	17.88	454.10 (506.3)	267.92	803.76
30	630.3	13.41	191.57 (172.8)	113.03	339.09

$P = 0.5 \times \rho \times A \times V^3$ (references 7 and 8), where ρ is the density of air (1.225 Kg/m^3), A is the windmill area perpendicular to the wind (0.1297 m^2) for a fan with a diameter of 16 inches and V is the velocity of the wind in m/s. The Betz limit is 59%.

As is evident from Tables 1 and 2, the Newtonian equations yield values of power that agree within 2% of the values obtained from the HAWT model. The values from the HAWT model were used to calculate the power contribution of the radiator fan wind turbine to the single family home energy consumption.

Since we could not measure the power output from a radiator fan installed in a vehicle traveling at 60 Mph, we measured the power from a generator (Figure 1) instead at lesser Wattage than would be generated in the vehicle. We reasoned that if the power extrapolated from this low Wattage (20 W) were to be in agreement with our calculated numbers using the HAWT equation, those calculated values of power in Table 2 would be reasonable estimates of the actual power generated by the radiator fan. In other words, we pursued extrapolated empirical values as evidence for reasonable estimates of power calculated at higher Wattages. For this purpose, we generated RPM versus volts and RPM versus amperes plots using the 20 W generator (Figure 3). Using these, we calculated the power output for a series of wind velocities, as shown in Table 3.

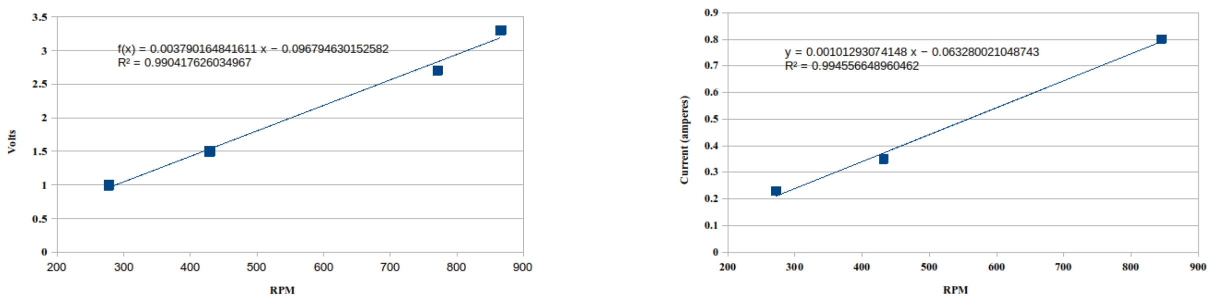

Figure 3. The relationship between RPM and electric potential difference measured in volts (left) and current measured in amperes (right). The numbers were obtained using the 20 W generator.

Table 3. Power output determined from the 20 W generator

RPM	Mph (wind speed)	m/s (wind speed)	Volts	Amperes	Power (W-h)
271.9	12.9	5.77	0.93*	0.23	0.21
277.9	13.2	5.90	1.0	0.22*	0.22
429.5	20.4	9.12	1.5	0.37*	0.56
771.5	36.7	16.41	2.7	0.72*	1.94
845.4	40.24	17.99	3.1*	0.80	2.48
865.9	41.2	18.42	3.3	0.81*	2.67

*The variable was calculated from the relevant equation in Figure 3, Power = volts*amperes,

Figure 4 shows the experimental results of power generation at the speeds obtained from the 20 W generator (red), or those calculated in Table 2 calculated using the HAWT equation (blue) plotted against the power generated in W-h. The values of the W-h obtained from the 20 W generator were multiplied by a factor of 100. The objective of the graph is to show that the calculated values of power generation for the wind speed range in Table 2 are reasonable estimates, and that a generator rated at 2 kW (100 x 20 W) per fan, should produce the Power calculated in Table 2.

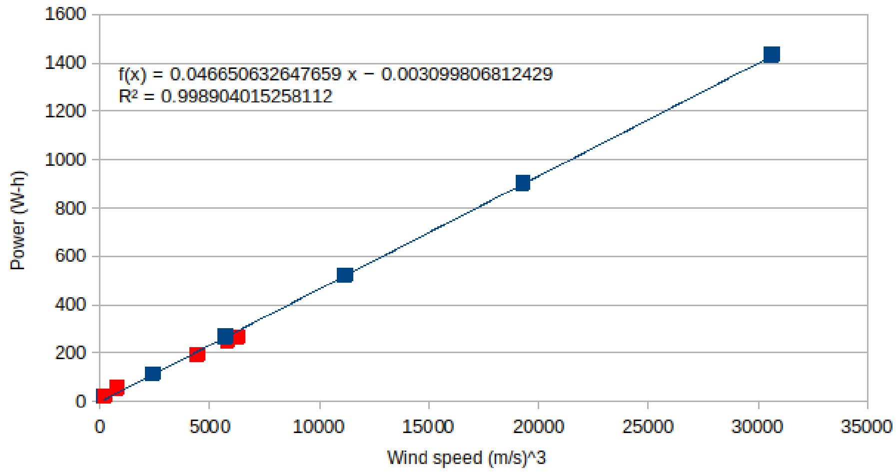

Figure 4. Power output experimentally obtained using a 20 W generator (column 6, Table 3, multiplied by 100, red squares) overlaid on those calculated from the HAWT equation in Table 2 (column 5, blue squares).

In Figure 4, the wind speed was raised to the power of 3 to align with the HAWT equation for the calculation of power (notes from Table 2). This suggests that the power output using a 2 kW generator calculated for a vehicle moving at 60 Mph using a 16 inch radiator fan facing the wind is likely to be a true representation of the actual power generated, based on the experimentally determined power output from a 20 W generator model.

Assuming that a third of the driving time is spent driving at 30, 40 and 50 miles per hour; the total power per fan per day generated by a vehicle being driven for 1 hour is calculated as P = [(1569.84/3) + (803.76/3) + (339.09/3)] = 904.23 W-h. For 3 radiator fans per vehicle, this translates to 2712.7 W-h per day or 2.7 kW-h per day per vehicle.

Table 3. Contribution to single-family home energy consumption

W-h per day generated by 284 million vehicles with 3 radiator fans per vehicle	Number of single family homes powered per day (24 hours)	Number of single family homes that can be powered for 3 hours per day	Number of days driving required (at 1 hour per day) to power 82 million homes for 3 hours per day
2.57×10^{11}	8.82×10^{6}	70.56×10^{6}	1.16

Average W-h of power consumed per day in a single family home = 29130 (2), Number of single family housing units in the USA = 82 million (9), number of vehicles on the road per day in the USA = 284 million (10), average time spent driving per day = 1 hour (11). Number of radiator fans installed per vehicle = 3, hence 904.23 W-h per fan per day are generated by every vehicle.

Hence a day's worth of driving by 284 million vehicles can power 10.8% of all the single-family homes in the USA round the clock, or 86% of all the single-family homes in the USA for 3 hours. To take the example of a medium sized city, Austin, which has 276611 single family homes; a day's worth of driving can power all the single family homes in Austin for

31.9 days, or approximately a month. The number of days required to power all the single family homes in the USA for 3 hours per day and for 24 hours per day (round the clock) was calculated to be 1.16 days and 9.3 days respectively. This represents $1/10^{th}$ (10.8%) of the total energy consumption per day of single family homes in the USA; a not insignificant amount; especially considering that the energy is largely generated free-of-cost.

A 12 V, 230 AH deep cycle battery can be mounted in the space between the radiator and the engine block as shown in Figure 2. In 1 day, it will have accumulated 2712.66 W-h of power from the 3 radiator fans. Assuming an 80% depth of discharge (DOD) to the grid, 2170 W-h can be uploaded to the grid at the end of each day by one vehicle. Two scenarios can be constructed. In scenario 1, the vehicle discharges to the home, thereby providing 7.5% of the home's daily power consumption. In scenario 2, a total of 2.57 X 10^{11} W-h can be uploaded to the grid every day by all the vehicles in the USA, enough to power 8.82 million single family homes round the clock with electricity (10.8% of the US single family housing stock), or 70.56 million single family homes with power for 3 hours per day; representing 86% of the total single home stock in the US.

Carbon neutrality (energy offset) calculations

Each 16" radiator fan weighs 2.7 Kg, each 2 kW generator weighs 20 kg and a 12 V 230 AH deep cycle battery weighs 70 Kg. For every 100 Kg reduction in the weight of a vehicle, its fuel consumption is projected to decrease by 0.4 L for every 100 Km traveled (12). Statistics show that a person spends an hour behind the wheel every day and travels approximately 39 miles per day (14300 miles per year) (13). Assuming that fuel consumption increase due to an increase in weight is similar to the consumption decrease due to a weight decrease, it can be calculated that one vehicle will consume an additional 0.22 L of fuel per day due to the weight increase originating from the three radiator fans, the three generators and the 230 AH battery. This translates into 6.2 X 10^7 additional Liters of fuel consumption per day for 284 million vehicles. It requires anywhere from 4 kW-h to 13 kW-h of energy (1,3,12) to extract and refine one gallon of oil. We used the figure quoted by E. Musk of 5 kW-h in this paper. Hence, it requires 8.2 X 10^8 W-h per day to refine this additional quantity of oil. Since the total electricity produced per day from the radiator fans is 2.57 X 10^{11} W-h, this implies a net positive energy output ratio of 313. In other words, the total energy produced by the radiator fans is ~300 times more than the energy required to power the extra weight of the vehicle. Expressed differently, our radiator fan wind turbine idea produces 99.7% more energy from a renewable source (wind) than it takes in from non-renewable sources (oil) to power it. This implies the generation of almost free energy, an unheard of paradigm in the renewable energy harvesting field. This does not include the energy required to manufacture the battery, radiator fans and generators.

The energy input and output can also be compared in terms of greenhouse gas (CO_2) generation. Since electricity production using coal and oil refining produce the same amount of CO_2; i.e. 2.3 pounds of CO_2 per kW-h (14) generated or consumed, the process of generating electricity using radiator fans is also CO_2 negative, generating ~300 times less CO_2

than if the single family homes received 100% of their electricity requirements directly from the fossil fuel-powered grid.

Discussion

Though ways for the car itself to produce energy in such a way had never been tested, there already exists a method to upload power from a vehicle to the grid. This is termed V2G (Vehicle-to-Grid) (15). V2G technology had already been recognized for modifying bi-directional charging, allowing users to upload energy from the car's battery into the grid. The implementation of this system, alongside the energy produced from the retrofitted fan, had been considered to utilize the vehicle's energy for grid upload.

Tax incentives and on-the-go rewards could be implemented to encourage adoption of this paradigm. A vehicle could be retrofitted at the point of purchase, at automobile shops, parts outlets or sold as DIY kits. The completed product can be designed to be user friendly, with only a need to plug in a (dis)charger into a port in the body of the vehicle; much like the port that is used to charge electric cars. A deep-cycle battery replace indicator can be installed on the dashboard to enable the user to remember to replace the battery every 5.5 years. Gas stations can be modified so that there is an upload cable available at each pump. Power can be uploaded to the grid simultaneously, while the vehicle is being filled with diesel or gasoline. The burden on drivers would not be too onerous, being only required to quick-connect the upload port while filling up. Drivers could be rewarded in points based on how much power they upload to the grid. Multiple uses can be envisaged for these points. They can be used to obtain fuel discounts, to contribute toward offsetting CO_2 emissions (in the form of carbon credits) of consumer selected company(ies); which in turn will provide the consumer with product discounts, to buy cryptocurrency associated with the carbon credit market, or to simply reduce the electricity bill. The points can be used at the time of uploading the charge or saved to be used at a later date in the form of an app, which should also keep track of points earned and spent. Gas station companies can compete to get the most electric charge uploaded at their station by raising the value of each point and providing special gas station cards with more incentives to bring customers to their station like people do for credit cards today. The radiator fan wind turbine paradigm hence also has the potential to drive a plethora of downstream commercial and consumer applications.

This technology is fuel or energy source agnostic. For example, it can be implemented just as easily in electric vehicles as in gasoline or natural gas powered ones. The only difference would be that the fan would not be cooling the 'radiator' in the former install, because electric vehicles do not require cooling. This is important, because it implies that the switch to electric vehicles or e-mobility will have no effect on the amount of power generated using this paradigm. Furthermore, for electric vehicles, there may be a design advantage that could incorporate the charging and discharging into a single port; wherein it may be envisaged that a simple flick of a switch could enable either of the modes to activate. The charging stations for electric vehicles may also be retrofitted to enable discharge to the grid.

Another use of this technology is to use the energy generated by the fan turbines to charge the drive battery in electric vehicles (if the fan is installed in an electric vehicle), rather than to upload the energy to the grid. As an example, the Tesla Model S has a battery capacity of 114 kWh. The challenge is that the 2.7 kWh produced per day using the fan turbines is too less (< 2.5%) of the Tesla battery capacity. While it may make sense to wait until enough charge has been accumulated due to the fan turbines, that option would require that the fan turbine battery hold a charge of 114 kWh; at which point, it makes more sense to swap out Tesla batteries or to recharge using the grid at electric recharging stations.

Limitations

The 12 V 230 AH battery will need to be discharged every day. This implies that scenario 1 presented under the Results section above is more likely so that each vehicle will discharge at home to the grid. If the homeowner takes an extended road trip away from home, they will then need to upload to the grid. This necessitates that the homeowner either own or lease the V2G or equivalent technology so that the power can be uploaded to the grid. It must be noted that it is not necessary that power be uploaded to the grid every day. In the event that it is not, no more power will be stored in the battery until such time that uploads start again. Assuming a lifetime of 2000 cycles, the battery will need to be replaced every 5.5 years.

The technology must not be too onerous to use. The power stored must be capable of being uploaded quickly to the grid. This time should be the same as the time it takes to fill the gas tank; i.e. approximately 1-2 minutes. It may be possible to achieve this because the quantity of power to be uploaded is small (< 3 kW-h). There should be reasonable assurance that the grid will not deny this upload due to load balancing challenges, at any time, at any gas station, in any large center of population. There seems to be no minimum W-h requirement for feeding power into the grid, the only challenges that the literature and public domain report, is that the utility meter may not register power < 10 W-h (or some minimum power) due to instrument precision.

Although the Betz limit was taken into consideration when calculating the maximum power that could be provided by the radiator fans, other losses such as electrical and transmission loss, generator loss, loss due to friction and heat etc. were not considered. The power that is ultimately uploaded to the grid may hence be lesser than that calculated in this work, but is unlikely to significantly mitigate the considerable contribution provided by the radiator fan wind turbines.

The combined masses of the three 16” fans, the three 2 kW generators, and the deep cycle battery will add 140 Kg to the weight of a typical 1520 Kg sedan. This represents > 9% by weight of the vehicle and is hence expected to cause increased wear and tear of the tires as well as increased fuel consumption (discussed above). Using the BMW 4 series coupe as a representative example, the width of an average coupe is 6.2 feet. Using 20 inches square for one fan (fan + housing), the total width required to house three 16” fans is 5 feet. This means that the set up of three 16 inch fans can be accommodated in all makes of gasoline or diesel cars without modifications to the existing engine and/or radiator placement. The average dimensions of a 2 kW generator (at ebay.com) are 2.7 feet by 1.5 feet (Figure 5). These generators can be mounted to the inside side chassis with a right angle bevel gearbox so that the space between the front grille and radiator need not be increased (Figure 2).

The assumption that the wind velocity is equal to the speed of the car may not be true because of the resistance encountered due to the car front grille and the limited area of air flow into the front of the car. However, an appropriate gear train can be installed so that the reduction in the wind speed due to the front grille can be compensated for. The power generated at 220 V AC can be fed to the car's inverter (alternator) which then can convert it to a 12 V DC output suitable for storage in the deep cycle battery.

Figure 5. Dimensions of an average 2 kW generator (from ebay.com)

Conclusion

To our knowledge, we are the first to propose the idea that radiator fans in automobiles can be used to convert wind energy into electricity. The relatively small fan blade diameter is more than compensated for by the significantly increased speed of the wind that the mobile vehicle encounters. Our idea thus effectively converts all moving vehicles into wind turbines and is potentially infinitely scalable. Our calculations show that one day's worth of driving (with a driving time of one hour per day) by 284 million vehicles in the US, each fitted with three 16 inch, radiator fans (rated at 2 kW each) in front of the radiator moving like pinwheels when the vehicle is in motion can generate and store 2.7 kW-h per day per vehicle in a 12 V 230 AH deep cycle battery. This stored power, when uploaded at 80% DOD to the grid using V2G or equivalent technology, is equivalent to 7.5% of the energy usage of a single family home per day. Even with the increased fuel consumption per vehicle, due to the increased weight of the battery, and the radiator fans with generator(s), the CO_2 footprint is net negative; generating ~ 300 times less CO_2 than if the single family homes received 100% of their electricity requirements directly from the fossil fuel-powered grid.

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