A Strategy for Electric Vehicles in Ontario

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Summary

A suitable combination of wireless and computing technologies is the most effective way of maximizing the benefits possible from the widespread introduction of electric vehicles when addressing the twin problems of the peaking of world oil production and potentially dangerous changes in climate resulting from the excessive emissions of carbon dioxide to the atmosphere from the fossil fuels. From the point of view of the consumer, a good combination of these technologies offers a lower cost and a more reliable electricity supply than would otherwise be the case; from the point of view of the supplying utility, this combination permits a better way of coping with a major new load by using to better advantage the large aggregate storage capacity provided by the batteries on board the vehicles particularly when the new supply at margin is obtained from a mixture of generation from inflexible base-loaded nuclear energy and a highly variable contribution from a growing number of wind turbines.

At the heart of the present proposal is a new technique for the control, metering and billing of electricity supplied to an expanding fleet of electric vehicles. Only very minor changes are needed to the existing network to separate the physical supply system from a virtual system directed only towards meeting the needs of the vehicles themselves. With this division of function, it becomes possible to design a rate structure applicable to the vehicles alone independently of the rates that apply to the rest of the system. Nor does this proposal interfere with any other measures contemplated to reduce peak demand and, in fact, the proposed measures may be readily coordinated with Smart Meter programs and the like applicable to the existing conventional load.

The basis of the proposal depends upon what is termed here a `Designated Plug' where the vehicles may be connected to a normal electrical outlet anywhere on the existing network but the bill for the energy supplied to the batteries is posted only to an account opened for each electric vehicle regardless of where it may be plugged-in. This is achieved by the software in the following way: when the car is plugged into such a designated outlet, the electrical contact initiates a Charging Session on the central system computer through the wireless system which may be of the cell phone type. This new file is numbered by the Vehicle Identification Number (VIN) which appears on the dashboard of every car sold, although nothing prevents the use of some other identification system if more convenient. The car then determines the number of the Host's meter - all meters in the present system have a number to which the electricity is billed. This may be done conveniently by mounting a passive Radio Frequency Identification Tag (RFID) on the surface of the Designated Plug. This is the only major change necessary to the existing electrical supply system. Once the car opens a new file on the central computer to start a

new Charging Session, a radio frequency beam generated on the car excites the tag on the plug and the resulting return beam conveys the Host Number to the receiver on the car. This second number is then transmitted to the open computer file. On receipt of these two numbers, the car then sent one of three possible instructions from the computer: the usual signal, `proceed to charge' (a green light might appear on the dashboard); the less frequent signal, wait for further instructions (yellow light); or more rarely at times of system crisis, send energy back to the grid (red light). (Bluetooth technology or Bar Code readers could also be employed to ascertain the Host meter number.) When the car is unplugged to return to service, the Charging Session ends with the reading on the on-board wattmeter transmitted to the computer. The quantity of energy transferred to the vehicle during the Charging Session is then posted to two accounts in what is in effect a double-entry bookkeeping operation: this energy is billed to the monthly vehicle account but also deducted at the same time from the Host's account with this adjustment appearing on the bill resulting from the routine monthly reading of the Host's meter. This latter meter measures the consumption of all the energy that passes through it consumed for all purposes – from both normal use and from the cars that may have been plugged-in. In the event the Host provides more than one Designated Plug, as might a shopping mall or parking garage, each car finds the same number on the Designated Plugs with the result that each car is billed separately according to its VIN numbers for the energy each has taken aboard, but the total of all these separate amounts are deducted from the same Host's account.

The Independent System Operator (ISO) knows from the central computer how many cars are plugged in any one time and the state of charging of each. The extent of battery charge might be expressed in tenths of the total capacity and this status transmitted periodically during the Charging Session. It is then possible to apply a search-type algorithm to determine how many cars are plugged in at any specified level of charge in perhaps less than half a second. This information allows the ISO to allocate the uncommitted energy available at that time to the cars least charged. It is quite conceivable that a million vehicles could be plugged-in during peak daylight hours in the parking lots of employers of which perhaps one quarter might be low on charge. For a modest vehicle charge rate of one KW, the ISO could then allocate 250 MW if it became available from the operational reserve or from unexpected additional supply from wind turbines. It is an important advantage of the separation of the physical supply system from the billing process in that energy can be supplied to vehicles through the Host's electrical connection at a low interruptible rate even if the Host is paying peak rates at the same time.

The cars that are covered by the supply contract may be re-charged at any Designated Plug located anywhere in the Province served by the ISO. There are two main incentives to buyers to sign such a contract at the time of purchase of an electric vehicle: to have access to a great number of Designated Plugs throughout the Province, and to purchase power at favourable interruptible rates as available even at peak times. In return, the contract would require that the vehicle be kept connected as much of the time as possible (minimum perhaps 300 to 350 hours a month) so that the collective battery capacity of all the connected vehicles could absorb energy when more can be generated than expected and, in extreme situations, such as late in the afternoon of a hot day in summer, could be used to send energy back to the grid.

The rapid progress in the development of batteries, especially those of the lithium-ion type, suggests that a large number of hybrid and all-electric vehicles could be on the road within a decade or so. Taken together, these vehicles constitute a major new load on the existing electrical system which must eventually be supplied by new generating capacity. However, the collective battery capacity of these cars is also large, and, given a suitable billing system for the power consumed, it is possible to envision an electrical system of greatly improved efficiency with the off-peak periods effectively utilized despite the difficulties of operation with increased shares of nuclear (inflexible) and wind energy (variable) in the supply mix.

Introduction

This paper examines the system requirements for the control, metering and billing of the electricity needed for a major option involving the introduction of electric vehicles of all types in Ontario, including those of the Plug-In Hybrid type (PHEV). The specific requirements set out here follow a more general proposal published previously in the Proceedings of the Canadian Association for the Club of Rome in November of 2007.[1]

The introduction of electric vehicles would address both the problems arising from the impending peak in the world production of oil and those resulting from the need to reduce emissions of greenhouse gases from the fossil fuels leading to dangerous climate change. The success of such an approach depends critically upon current efforts to develop lithium-ion batteries suitable for automotive applications, but current progress is encouraging.

Placing a large new load on the existing electrical system raises many issues. The scheme proposed here accommodates increased inflexible generation from nuclear sources in base load mode as well as more unpredictable generation from the wind by effectively utilizing the large storage capacity in aggregate provided by the batteries in electric cars. New software may be required but existing wireless technology may be sufficient to meet the needs of this proposed system.

This proposal is timely in view of the present difficulties faced by the automotive industry in Ontario. It is a major opportunity for the Province that may well qualify for some measure of government support for its development.

Electric Vehicles and Cell Phone Technology

The number of licensed vehicles and cell phones in service in the Province are broadly comparable in number. As of 31 December 2007 there were 6,339,389 passenger and 1,287,493 commercial vehicles registered as well as an additional number in specialty classifications including 31,743 buses.

Statistics Canada reported in the 2006 Census that 71% of the households had at least one cell phone. Since there were a reported 4,972,869 households in the Province, there were at least 3.56 million cell phones in operation at that time and no doubt even more now. There are at least three cell phone networks that cover the Province fairly completely. These networks are already well developed and current expansion is focused on the filling of dead spots. There is thus reason to believe that electric vehicles in the Province could be served in some way by the existing cell phone network or something very similar: the necessary software is already in place and it should also serve this new purpose with only relatively minor modifications because there are no extraordinary demands on the computer hardware.

Province-wide Wi-Fi networks could also be used for this purpose. Cell phone networks may be considered as serial and Wi-Fi networks as parallel approaches and there is no reason both could not be used individually or by working together if necessary.

The Province-Wide Designated Outlet Plug

The universal province-wide outlet is at the heart of the new strategy and is termed here the Designated Outlet Plug. When the driver plugs his car into such a Designated Outlet, the on-board cell phone system contacts the central control computer and sends the Vehicle Identification Number (V.I.N.) now mounted on each car's dashboard though some other similar identifier could be used if more convenient. The computer then opens a new Charging Session with each of these numbered sequentially over the monthly billing period for every vehicle. The next step is to transmit the number of the Host of the Designated Outlet Plug as elaborated below. When these two pieces of information are received, the computer instructs the car to take one of three possible steps depending upon the status of the electrical network. In the normal case, the car is permitted to begin charging immediately and a green light comes on in the electronic box mounted in the dashboard. In the less likely case, the car is signalled to wait for further instructions with a yellow light indicator, and in the exceptional case, the car is called upon to send energy back to the grid which is signified by a red light.

The act of disconnecting to resume travel signals to the computer that the Charging Session is completed. This closing signal includes a reading of the wattmeter on the car informing the computer of the quantity of energy that has been transferred during the Charging Session just completed. This amount is expressed in energy units and is posted both to the accounts of the car and the Host in an action equivalent to double-entry bookkeeping. In the normal case of charging the vehicle off-peak, this quantity of energy is added to the account of the car and subtracted from the account of the Host. (The special cases of on-peak charging and return of energy to the grid will be discussed below separately.) With this procedure, it is possible to charge the car from any Host in any location in the Province under the purview of the Independent System Operator so that the cost for the energy loaded into the car battery is posted only to the monthly bill for the car. Though this energy has passed through the meter of the Host, this reading is effectively adjusted by the deduction made by the computer. With this procedure, the Host is the physical provider of the energy that flows through the Designated Outlet to the car but does not pay for it.

This separation of functions allows a virtual electric supply market to develop to power the electric vehicles which will be explored further below. The major advantage in this procedure is to allow a different pricing system to apply to the cars, with their significant total electrical storage capacity, than that paid by the Host even though the energy has passed though the same meter. In effect, the electric vehicles will be supplied with interruptible power priced on reduced terms because of the independent command instructions possible using the cell phone-type connection.

When the car is returned to its base at home, the owner has a choice. He can connect into a designated plug at his house and the bill for the energy transferred will appear on the monthly account for the car, or he can opt to plug into an outlet without starting a formal Charging Session and pay the electrical charge on his normal household bill. However, the terms to be discussed in the section on Contractual Arrangements are such that using a Designated Outlet at home will be more attractive. Moreover, having such outlets available for the use of visitors, and perhaps contractors working on site and others, means that offering this service does not involve incurring an expense for the electrical energy provided. It may become a social norm to provide a Designated Outlet for visitors.

The outlet itself is the normal outdoor quality electrical box. A major advantage of this procedure is that the only modification needed to the entire electrical distribution system is an electronic identifier placed on the outside of each outlet. The most convenient way of doing this is probably by using a passive and low cost Radio Frequency Identification (RFID) tag such as are now attached to garments and other items in department stores to discourage shoplifting. The tag is radiated with a beam generated from the car after electrical connection is made, and this stimulation results in a return beam carrying the identification number of the outlet. This latter number in effect tells the computer where to deduct the energy supplied through the Designated Outlet Plugs. A shopping center or major employer may have many of these boxes - all with the same identifying number - in their parking lot, but nothing more than the existing meter is required except that it should have the ability to operate backward when the vehicles are called upon to return energy to the grid. It is termed here the Host Meter which is read as now once a month or so to provide the information required to calculate the bill for the electrical service. This bill does not include the cost of energy transferred to the various vehicles that may have been plugged into the Host's Designated Outlets during the month because the quantity of energy taken on board each car is deducted before the bill is computed. The bill is then prepared using the standard rates that apply to the Host for his normal (non-car) electrical requirement.

It is envisaged that a `surround' plate would be attached around the conventional outlet perhaps as a force-fit that could be brightly coloured, and might include a distinctive crest to help identify eligible outlets to passing motorists from a distance. The only difference between a Designated Outlet and a normal outside plug is thus the ability to respond to a query from the car to provide the number of the Host. It is possible the `surround' could also carry advertizing in the case of retail stores, or in the parking lots of shopping malls, etc.

Other methods of obtaining the identification number of the Host include the use of bar code systems or dedicated Bluetooth transmissions. Because of the complications arising from winter conditions (piled up snow may interfere with reading the RFID device on occasion), the capability of entering the Host number manually into the electronic box in the car for transmission to the central computer should be provided. Shopping malls might post their number on a conveniently located sign which again offers the opportunity for advertizing space.

The monthly bill payable by the vehicle owner would resemble a credit card account. In the usual case, there might be 25 to 60 separate items listed which might total in the $25 – $60 range for the month. Most individual items would be small, often a number of cents, for separate charging sessions of a few hours at one kilowatt or so input. Because the individual items are of this order, there would be no strong incentive to pursue the inevitable errors that may be expected to arise from time-to-time. Only persistent systematic discrepancies would be worth checking in detail. The monthly bill presents other commercial opportunities especially in the field of car insurance to be explored below.

Contractual Arrangements

The question arises as to why purchasers of electric vehicles should contract for energy from this necessarily centralized system. Owners would still have the right to plug in to normal outlets and have the energy loaded appear on their household account like any other device that consumes electricity. Visitors with electric vehicles from other jurisdictions could recharge their batteries in this way. Nevertheless, there is a strong incentive to join the system because of two major factors. First of all the electricity would be offered at a lower price as it is supplied on an interruptible basis as available which includes some energy at peak times which would otherwise be expensive. Second, the contract allows access to Designated Outlets not only throughout the immediate network including connections at work, but in all parts of the Province as well. (The system could be expanded to other Provinces but this would require additional agreement. As time passes and the system becomes well established, it is quite conceivable that there would considerable pressure for reach agreements particularly in the Ottawa region.) It is envisaged that a PHEV might be driven to Toronto proceeding as far as possible under electric power at first and then the car would switch automatically to its engine when necessary. The battery might be recharged in part while the car is operating with its gasoline engine at the option of the driver. On arrival, the car might also be recharged at any available Designated Outlet, such as at a hotel parking garage, to permit limited local driving under electric power.

In return for power supplied at attractive interruptible rates, the contract would require, under penalties, that the car be plugged-in (that is, connected in open charging sessions) a certain number of hours per month, probably from 300 to 350 hours. The car may be recharged in this way as electricity becomes available but, in extreme cases, the car may be called-up to return energy to the network. If one million cars were plugged in to the network at any one time at a conservative energy transfer rate of one kilowatt, a load of one gigawatt may be supplied off and on as allowed by network conditions. Alternatively, the network could call upon the cars for up to one gigawatt to help meet unexpected peak needs. Algorithms exist in the search engine and other fields that can be applied to locate cars at different states of battery charge very quickly (for example, 200,000 vehicles might be found charged only to 30% capacity or less within half a second. These cars could then be instructed to begin charging which would constitute a nearly instant additional load of 200 MW).

An issue also arises to why businesses and others would make available Designated Outlets. In the case of retail establishments, shopping malls, hotels, motels, hospitals and commercial parking garages and the like, there would be a strong incentive to provide this service to attract customers particularly as there is no payment for the electricity transferred involved. Employers would no doubt take the same position to attract dedicated employees as they supply outlets already in some cold weather cities for block heaters. Nevertheless, some other incentive is likely required, and special terms for power might be negotiated with those that install a large number of Designated Outlets.

There is another reason this practice may be attractive. Because the cars are directly connected to their electrical system, the Hosts will have the first call upon the energy reclaimed from the car batteries in the event of an unmanageable peak. There are two cases: in the first, the amount of energy recovered from the cars is less than required by a Host (such as might be the case for a large shopping mall) who in this circumstance is billed for the energy taken in from the cars plus that what is still coming in through the normal metered supply line; whereas in the second case, this quantity is more than required by the Host (such as might be the case for a parking garage) such that the Host meter would run backward. In this second case, the latter Host would be charged for the energy coming in from the connected cars but automatically credited for the amount transferred back to the distribution system by the reversing meter.

Commercial Opportunities in the Electric Vehicle System

The main related commercial opportunity is in the field of car insurance because it now becomes possible to offer a more rational fee structure which could be paid on the monthly bill.[2] The computer knows when the car is connected to a Designated Plug. The car is thus immobile for this period of time. An insurance rate for different categories of vehicle could be established on a daily or even hourly basis for the time the car is disconnected (calculated by difference) and thus available for normal driving service. This time could serve as a surrogate for the distance driven, or from the point of view of the insurer, the time the car was at risk on the road. This procedure is a much fairer way of providing car insurance than the present practice which does not take into account the actual driving time. For most people, the adoption of such an approach would likely result in a substantial reduction in yearly insurance charges coupled with a more convenient way to pay, stretched out as it is on a monthly bill. This method for the provision of insurance also offers an additional incentive to keep the car plugged-in as much as possible of the time, which is a major goal of the system operator.

Other commercial opportunities include the diagnosis and provision of repairs, offers of travel services, and the marketing of vehicle accessories. There is also a safety aspect since the cell phone system could be used to call for assistance both medical and mechanical, and serve as a deterrent against theft.

Nuclear Energy and Wind Turbines to Power Electric Vehicles

Nuclear energy and wind power share both a low operating cost and a high unit capital cost. Once installed, there is thus a strong incentive to derive as much energy from these sources as possible. In other ways, however, these two electrical sources have opposite characteristics. Nuclear power is steady but inflexible; wind power is inherently unpredictable. With the deployment of many electric vehicles giving rise to a major new load on the network, it is important to find an operating procedure that allows the best use of these two sources. As far as nuclear energy is concerned, the chief objective is to devise a system that has the least variation between peak and off-peak conditions. The smoother the load curve over the course of a day or a year, the higher the fraction of the load that can be supplied from nuclear sources in a given system. The advent of a workable procedure capable of turning the re-charging of electric vehicles on and off very quickly depending upon network conditions constitutes a major advantage. The present practice followed to smooth loads is to extend interconnections as far as possible with other generating jurisdictions. It is probable that the financial returns from the supply of interruptible energy to electric vehicles will be more rewarding.

In the case of the growing supply from wind turbines, the problem is how to cope with unexpected changes in generation due to variable wind conditions. The world installed wind generating capacity in March 2008 was about 100 GW and growing fast - most recently at the rate of about 30 GW per year. The wind is a maverick source of power: the only effective independent command that can be given is to stop generating. The problem is the unpredictability of supply given that generation depends upon the cube of the velocity of the wind at any one time. Even when using the best of the artificial intelligence programs now available, the most accurate generation estimate is about + or – 20% for an assessment made the previous day, the minimum planning period for the deployment of generating capacity. The record so far was achieved in Spain where in early 2008 a maximum of about 40% of the total system generation was obtained from the wind over one weekend but only 28% was the corresponding limit on a normal working day in that country. This is an interesting case given that the Iberian Peninsula is difficult to interconnect with the rest of Europe for geographical reasons. Despite these good results, it is noteworthy that the Spanish system operator has a policy of limiting contributions from the wind to 30% to maintain system stability. In most countries, it is difficult to generate more than 25% of the total requirement from the wind without a very wide interconnection system.

Electric vehicles can be used to help accommodate these sources of energy by using their batteries to the extent possible as the necessary storage buffer. The performance characteristics of lithium-ion batteries suggest the effective repetitive charging range is from a minimum of about 30% to a maximum of about 80% to maintain long life, or about half the nominal total storage capacity.

Environmental Emissions

In the short run, the effect of the introduction of electric vehicles in Ontario on overall emissions in the Province is problematic because there is sufficient installed capacity already to support a large number of electric cars (possibly as many as a million) by operating existing generation facilities more hours off-peak. In the early years as electric cars enter service, their needs can be met for some time by operating non-base load capacity fuelled mainly by consuming additional natural gas or coal, with the expanding wind capacity also providing an unpredictable share on any given day. In this situation, as far as greenhouse gas emissions are concerned, there is the possibility of an actual increase resulting from the deployment of electric vehicles; on the other hand, the other more conventional emissions, which are often the most troublesome in cities, would not be so much reduced as re-located to the sites of the these generation facilities. Nevertheless, there is still the possibility that the non-base load generation facilities may produce fewer emissions than would the conventional cars that are being replaced by their electric cousins despite the extra hours of operation of the fossil-fuel based facilities. The specific answer to this question depends upon the mix of generation facilities in service at the time of the introduction of the early EVs.

In the longer-term, the situation is quite different when additional generating capacity must be provided to meet the needs of both the new fleet of EVs and the growth of the other normal loads. With a smoother daily demand curve resulting from charging the EVs off-peak, nuclear energy could meet a higher fraction of the load than otherwise. Furthermore, with a system for the control of the plugged-in vehicles as advocated here, additional unpredictable energy from the wind could be more readily accommodated such that energy from the wind would not necessarily be limited to the present 25% or so.

Nevertheless, a major problem arises from the advent of an important new load on the existing electrical supply system such as would result from a major EV option. The most efficient scale of nuclear reactors is tending to increase, and this source of energy operates continuously in base load mode. The additional capacity from this source of energy inevitably comes on-line in large, inflexible quantities. There is thus a need for a non-carbon dioxide emitting generating capacity that may be introduced in smaller, more flexible sizes, and which can be operated intermittently as required. This author has recommended that oxygen-fired pulverized coal units of about 500 MWe size equipped for the capture and sequestering of carbon dioxide would best meet this need in Ontario leaving natural gas-fired combined-cycle facilities to meet peak loads. In effect, this new class of coal-fired facility would address base load requirements in between the in-service dates of a revitalized nuclear option as well as meet the normal shoulder load period for which they are well suited. A combination of nuclear and coal technologies of this kind would provide a superior approach to dealing with greenhouse emissions that fits well with a major electric vehicle option for the Province.

A special environmental problem also arises from the third-party conversion of hybrid vehicles to plug-in operation. The catalytic converter though which the conventional engine exhaust passes must be hot to be effective. Because the engine operates less frequently than anticipated by the designers after conversion to the plug-in mode of operation, higher conventional emissions result from its cooler operation. Presumably this problem may be addressed in production designs (as opposed to conversions) of plug-in vehicles by installing a heating device of one kind or another.

Functions Required of the On-Board Electronic Box

The recommended strategy for electric vehicles applies to all vehicles that may draw their energy from the grid whether in whole or in part. It applies to any design of vehicle or choice that may be made by the consumer. Nevertheless, all vehicles participating in the recommended strategy have to share a common set of instructions from a central electronic control. The attributes of the on-board electronic box include:

- The capacity to communicate with the central computer whether using cell phone or Wi-Fi technology with the message activated by the making or breaking of the electric power connection;
- A common integrated numbering system for both the vehicles and the Hosts;
- There must be a wattmeter although extreme accuracy of measurement is not required;
- It must know the time to deal with peak and off-peak periods;

- It must be able to receive and act on instructions sent by the computer although the commands are relatively simple such as: charge the battery; wait for further instructions; and return energy to the grid;
- It should be able to monitor and report on the status of the battery perhaps in terms of tenths of full charge though great accuracy is not needed;
- It would be useful to have a GPS unit integrated with the electronics so the location of the vehicle could be known to the central computer. The location of the vehicle when charging could be checked with the known fixed location of the Host to help find errors, to discourage the stealing of vehicles, and to help reduce the fraudulent consumption of electricity. The distance travelled between charging sessions could also be included;
- It may be desirable to turn heating systems on or off independently of battery charging;
- It would be desirable to have an interface, preferably graphical, such that Host numbers could be typed-in manually in case of difficulty and to override certain commands as made necessary by the circumstances;
- A simple means of communicating with the central computer system operator to deal with difficulties should also be provided (modified Instant Messaging?) with voice connection by an independent cell phone a last resort. Standard error message short forms might also be developed which could be displayed on the electronic box screen or transmitted back to the computer.

Because the need for electrical energy to operate the electronic box itself are small, it is probable the supply needed for this purpose should by-pass the vehicle power system connections and so not be monitored by the system watt-meter with the objective of improving system reliability. If so, this small amount of energy would appear on the bill of the Host but this minor error would result in a negligible extra charge.

In general, the commands required are simple and well within the capabilities of existing wireless systems. For the most part, although the despatch of messages should be prompt, there is no need for operation in `real time.' In fact, there may be a disadvantage in the immediate execution of commands. Plugging in the car under extreme winter conditions could well result in a few `make or break' connections before the contact was secure. A slight delay would allow for fumbles of this kind without starting and stopping a new charging session each time electrical contact was made. The minute or two that might be lost off a charging session is of no consequence. Because some time is available, established queuing programs of one kind or another could be employed by the computer to deal with a large number of messages arriving at once.

The only sequence of commands that may actually require an immediate response involves instructions to stop charging or return energy to the grid at the time of difficulties due to peak load conditions, or to accommodate unexpected extra energy supply from wind turbines.

With early adoption of this strategy, it is possible that Ontario could develop an industry manufacturing these electronic boxes that could supply others around the world.

Electric Vehicles in Winter

Severe winter conditions are not friendly to electric vehicles. However, because in this scheme the cars would be plugged-in much of the time when not in operation, there are some mitigating steps that could be considered. First of all, the battery system could be placed in an insulating bag equipped with heating elements as is now the case for standard batteries in cold weather regions. Another possibility is the use of ceramic-based heat storage units to provide cabin comfort. Such heat storage devices hold thermal energy in two different ways: first the ceramic allows the unit to be heated to a higher temperature and thus hold more sensible heat than most other such devices and second, it is possible to build a phase-change substance into the ceramic structure to substantially increase the amount of energy held. This energy is instantly available to the vehicle cabin as soon as the car is occupied. The electrical requirement for these devices may well amount to an average of 300-400 watts in cold weather and thus may account for a sizable fraction of the one to two kilowatts transferred through a conventional plug. It is simplest that this energy be bundled with that used to recharge the batteries and thus it would qualify for the same interruptible billing rates but other systems are possible.

The adaption of PHEVs for winter service may well be an area where Canadians could make an important contribution to this technology, particularly in a Province with an important automotive industry.

Asymmetric Pricing of Electricity

The ability to bill for the power consumed by electric vehicles under different terms than those applicable to other consumers in `real’ time is at the heart of this strategy even when the cars are connected to the same metered supply line. This capability opens the possibility of using the large storage capacity available in aggregate when there are many vehicles with batteries connected to the system to smooth out the load on the grid. The object is to use the generating capacity and the network that transmits this energy in a more optimal way.

It will be assumed here that normal household and commercial use of electricity will be subject to three tariffs depending upon the time of day. (Large industrial users already purchase their energy under complicated contractual terms). These times will be designated as off-peak (‘L’ for low), intermediate shoulder load (`I’ for intermediate), and peak (`H’ for high). The periods that these tariffs apply are set from experience and do not necessarily reflect the actual condition of the network at any particular time. Moreover, there must always be a margin for safety. From a programming point of view, the three rates, whose values would normally be set periodically by Regulatory Boards of one kind or another, may always be expressed as a factor of the one chosen as the base: for example, H may be 2.0 times the L rate with the I rate 1.5 times L. In general, the electric vehicles will pay the L rate regardless of the time of day on the grounds that this supply may be interrupted, or even reversed, at any time on demand.

The asymmetric pricing problem considered in this section arises when the Host is paying at the H or I rates though the vehicle(s) connected to the Host’s system are paying at the low L rate. Because all the energy for the connected cars passes through the Host's meter, without correction it would be billed at the rate set as appropriate to the time of day. Some adjustment is thus necessary. In a typical example, the car may be driven to the place of employment and plugged into the employer's Host system in the parking lot in the morning. The employer's billing rate may be at the H level for the typical peaks in Ontario for the early morning and late afternoon but reduced to the I level for the middle hours of the day. When the driver plugs his car in on arrival, a formal Charging Session begins but no energy will flow to the battery unless more is available to the network than expected by the System Operator. This holding condition is indicated by the yellow light appearing on the dashboard of the car. The connection is made because of the driver's expectation that at least some energy will be supplied during the day, and because a certain minimum connection time each month is necessary to qualify for the lower L rate at all times of the day. In a practical case, surplus energy may arise from the reserve safety margin set for the day and from the vagaries of generation from wind turbines on a windy day.

The System Operator may determine the number of vehicles connected at any time from the central computer. His duty (and art) is to match this information with the surplus generating capacity existing at that instant. For example, the Operator may find that of the million cars plugged in, the batteries in 200 hundred thousand are less than half-charged. If there is 200 MW available, the Operator may then allocate this energy to those cars. The algorithm required is similar in general outline to those employed by internet search engines and it should be possible to locate the eligible cars in less than half a second. These cars could then be allowed to re-charge for the time the surplus energy is available. WiFi technology with its inherently parallel approach is probably better for this purpose but cell phone sequential technology may be fast enough. The driver, walking though the parking lot on his way to his work, would then see yellow lights turn to green in some of the cars as he passes. The reverse signal would stop the charging procedure if load conditions changed unfavourably, and the lights would turn again to yellow. Using this class of algorithm as before, it is possible to `shed' the cars in reverse order to the extent of the charge on their batteries – those least charged would be dropped last.

The probable solution for the billing problem in this case is to have the watt meter in the vehicle make separate measurements of the energy transferred to the car for each time period H, I, or even L if the employee is working late. It can be programmed to do this because the vehicle knows the time. When the Charging Session is concluded by disconnecting the vehicle, the signal sent would provide the central computer with the information required to compute a simple total of the energy transferred in all three periods which would be added to the vehicle's account. An adjusted energy value would then be calculated for deduction from the Host's account. From a programming point of view, this correction might best be made by multiplying the energy transferred in each rate period – H, I or L – by the respective rate factors which might be 2.0, 1.5, with 1 a place-holder value in the L case. This adjusted sum of energy would then be deducted from the Host's energy account. By following this procedure, only energy units are used in the transmission of the billing information with the monetary values calculated later in the usual way: the corrected energy transferred needs only to be multiplied by the L rate to compute the Host's monthly bill.

The situation is somewhat more complicated when energy is required from the vehicle. The rates paid for this energy may be determined independently as before by the responsible regulatory board. There are two cases: in the first case, only energy extracted from the batteries is transferred back to the grid down to a certain residual minimum charge level (probably about 30%); in the second case, when there is a critical network situation as there might be late in the afternoon of a very hot summer day, the transfer requires the engine to start which results in the generation of electricity from gasoline at relatively low efficiency. Again these return rates may be expressed as factors of the L rate, say 2.0 and 5.0 for the two cases respectively. This adjusted energy value in this case would be posted as a credit to the account of the vehicle. The Host would pay for this energy coming into his establishment from the vehicle in unadjusted form in the same way as any other depending upon the time of day. If the energy coming in from the vehicles is greater than his own need at the time, this surplus would be exported to the grid at large with the meter running backwards. This presupposes that the meter in a time-of-day billing situation is able to cope with energy supplied back to the grid at different times of the day by making the appropriate credit.

References

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2. See *Not-So-Free Ride: Freakonomics,* by Stephen J. Dubner and Steven D. Levitt in the New York Times Magazine 20 April 2008.
3. Recent relevant general interest articles include: Kevin Bullis: *An Electrifying Startup,* Technology Review, Vol. 111 No. **3** (May/June) 2008; Anon: *Wind Power in Spain*, Technology Review, Vol. 111 No. **3** (May/June) 2008; and John Voelcker *Plugging Away in a Prius*, IEEE Spectrum May 2008.

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