The Hybrid Electric Car

by

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Thesis submitted in partial
fulfillment of the requirements
of Bachelor of Applied Science.

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1969

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FOREWORD

Electric power for automobiles came long before piston engines. The first electric car on record apparently was that of Davenport, a Vermont blacksmith who constructed an electrically propelled vehicle in 1837. This was only 44 years after Volta's first primary battery, and only 7 years after the principles of the first electric motor had been demonstrated by Negro at the University of Padua.

During the next hundred years many versions of the electric car were built but with the great developments in piston engines, including the development of the self-starter, the electric car was replaced and few were built after 1930.

Now the pendulum swings back. Once more electric automobiles are in the public eye, thanks mainly to the fact that they do not emit air pollutants. Electric automobiles offer other advantages for urban transportation: they can be small for crowded streets, nearly noiseless for residential areas, and extraordinarily convenient for stop-and-go driving. It is unlikely though, that electric vehicles will ever compete with piston-engined cars in performance. Hence, in the future, electric automobiles seem most likely to move about in the cities, while high powered, high speed, massive piston engined cars will still be used between cities and for general purpose driving.

CHAPTER 1

INTRODUCTION

A hybrid is defined as the enhanced offspring of the union and cross-breeding of the mature form of the male plant species (in this case the internal combustion engine) with the equally mature form of the female of another species (the electric motor/generator). The power package proposed for consideration here is a transitional intermediate between the all-electric and the all-combustive power supply. The hybrid system consists of an internal combustion engine of rating much reduced from the conventional motor that it supplants, driving at its optimal speed a generator. The generated electrical power goes to the traction motors and to a sizeable secondary battery, also connected with the electric motors. Solid state controls divert power from both the generator and the battery to the electric motors when the driver's power demand exceeds the capability of the constant speed engine. When the accelerator pedal demands less power than the internal combustion engine delivers continuously, the controls divert some power to the wheels and some to recharge the battery. If the battery becomes fully charged, a progressively lesser amount of fuel is metered out to the internal combustion engine.

The positive reasons for developing hybrids are twofold: first, they present an early capability for reducing exhaust pollution substantially by use of existing automotive technology; and second, hybrids promise a perceptible lowering of operating and fuel costs.

The hybrid's exhaust would be proportionately less polluting than its conventional counterpart for these reasons:

1. The power output of the internal combustion engine would be about one-half that of the engine it replaces. At a first approximation, this means one-half the air pollutants.

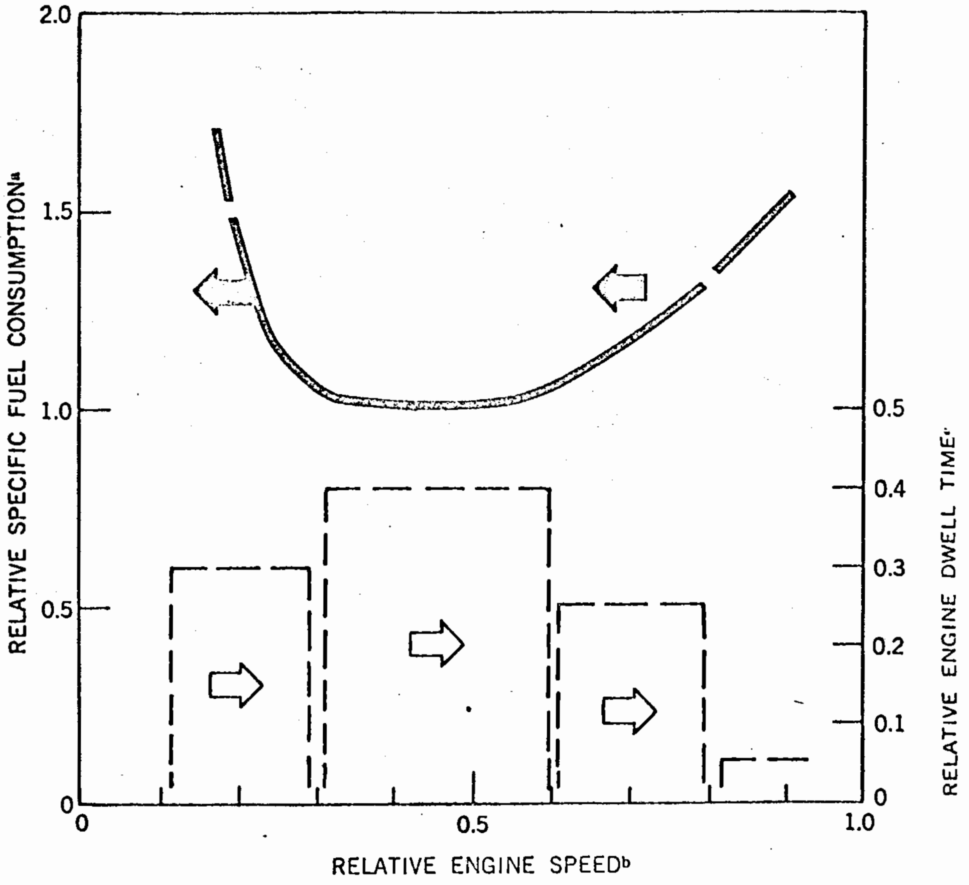
2. The engine-generator would be run at constant speed near the speed of minimum specific fuel consumption. A further pollutant reduction of one-third is approximated. Figure 1a shows that an engine dwells only 40 per cent of its operating time at its level of least specific fuel consumption which occurs at 0.3 to 0.6 of maximum rpm.

3. Fixed-speed internal combustion engines allow most easily the incorporation of regenerative heating of inlet air by recirculation of exhaust gases. This process leads to a reduction of unburned hydrocarbons and nitric oxide produced in the combustion chamber. It could amount to a further reduction of one-half.

Thus we see that a well engineered hybrid power pack could be one-fourth to one-eighth as emissive of smog products as its equivalent piston engine.

The second class of beneficial contributions from hybrid power systems is lowered operating cost. Without changing the driver's power, demand for performance, speed, acceleration and grade climbing, fuel consumption could be slashed one-third just by constant speed operation of the engine (note figure 1 a). Cheaper and less refined fuels than those presently required can be used on constant speed engines. In sum the full cost might be one-half to two-thirds that for conventional automobiles.

Maintenance costs of hybrids also may be lower. Generator and gas engine on the same shaft means basically one moving part. Non-mechanical power transmission to the wheels allows for easy power plant plug-in and replacement, less destructive vibration and freer interchange of parts. Hybridizing the power system of the automobile also buys a few decades of time for the more orderly research and development of individual travel means, and a more gradual introduction of the driving populace to electric propulsion. Also the quiet hum of the turbine-generator-motor might prove a less offensive sound than the muffled roar of the V-8.



[a] $$\text{RELATIVE SFC} = \frac{\text{SFC AT rpm AND MAXIMUM TORQUE}}{\text{MINIMUM SFC}}$$

[b] $$\text{RELATIVE SPEED} = \frac{\text{rpm AT SPEED}}{\text{rpm EQUIVALENT OF 120-mph ROAD SPEED}}$$

[c] FRACTION OF ENGINE TIME AT rpm IN AN URBAN TRIP COMPENSATED FOR IDLING TIME AND BRAKING BY ENGINE DRAG

Figure 1a.

CHAPTER 2

POWER REQUIREMENTS

"I believe that the future electrically propelled vehicles should be a look-alike, act-alike, simple counterpart of the piston engined vehicle with comparable dimensions, performance, and speeds."

(G. A. Hoffman 1967
University of California)

Power must be provided in an automobile for both propulsion and accessories. In general, propulsion power is applied to raise the kinetic and potential energies of the car and to overcome frictional and drag forces. The stored energies are potentially recoverable but frictional energy is not.

Modern tires allow a comfortable ride but they consume a significant amount of energy. Tire rolling resistance is a function of a number of parameters, including specific tire design, materials of construction, tire diameter, car weight, vehicle speed. Figure 2 a shows the approximate energy requirement in kilowatt-hours per mile to overcome tire rolling resistance for variations in car weight and rolling coefficient.

Energy is also consumed by aerodynamic resistance. Figure 2 b shows these energy losses for various drag coefficients and frontal areas of cars. Of course, aerodynamic drag is strongly dependant on speed. Figure 2 c shows the effect of speed on the air drag losses of the typical modern car. Table 2 d shows acceleration requirements of various cars to various speeds.

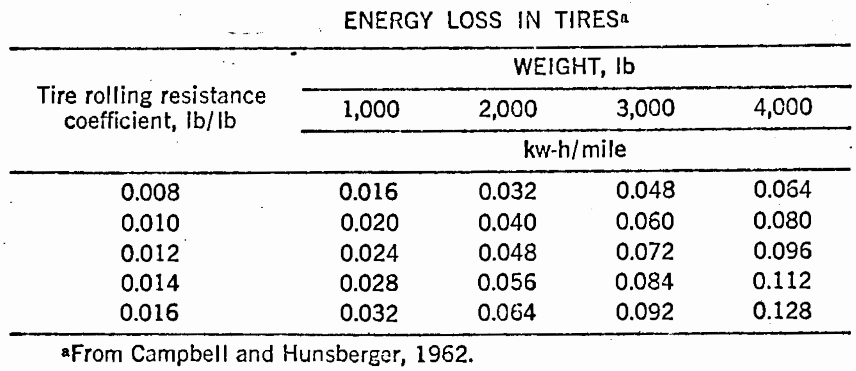
Requirement for accessories can vary widely from a few watts to several kilowatts. One of the major power consumers (especially in the Canadian climate) is the heater - approximately 25,000 B.T.U.'s per hour - 7 kilowatts.

Total energy requirements for various driving modes are examined in table 2 c. Three types of driving are considered:

1. Urban - average speed 15 mph; 5 stops/mile
2. Suburban - average speed 30 mph; 1 stop/mile
3. Highway - average speed 60 mph; 0.01 stop/mile

The totals in Figure 2 e can be considered as understated since no allowance is made for accessories.

Figures 2 f and 2 g show the Power and torque needed to drive a car at various speeds.



ENERGY LOSS IN TIRES[a]

Tire rolling resistance coefficient, lb/lb	WEIGHT, lb 1,000	2,000	3,000	4,000
	kw-h/mile			
0.008	0.016	0.032	0.048	0.064
0.010	0.020	0.040	0.060	0.080
0.012	0.024	0.048	0.072	0.096
0.014	0.028	0.056	0.084	0.112
0.016	0.032	0.064	0.092	0.128

[a]From Campbell and Hunsberger, 1962.

Figure 2a.

ENERGY LOSS DUE TO AERODYNAMIC DRAG[a]
(at constant 35 mph)

Air resistance coefficient, lb-hr^2/(ft-mile)^2	FRONTAL AREA, ft^2			
	15	20	25	30
	kw-h/mile			
0.0006	0.022	0.029	0.035	0.046
0.0008	0.029	0.039	0.047	0.059
0.0010	0.037	0.049	0.059	0.074
0.0012	0.044	0.059	0.071	0.088
0.0014	0.051	0.069	0.082	0.103

[a] From Campbell and Hunsberger, 1962.

Figure 2b.

ENERGY LOSS DUE TO AERODYNAMIC DRAG[a]

Speed, mph	Energy Loss, kw-h/mile[b]
10	0.005
20	0.019
30	0.048
40	0.077
50	0.120
60	0.173
70	0.235
80	0.307

[a] From Campbell and Hunsberger, 1962.

[b] Aerodynamic drag coefficient of 0.0012 and frontal area of 20 ft^2 are assumed.

Figure 2c.

ENERGY REQUIRED FOR ACCELERATON

Vehicle speed, mph	VEHICLE WEIGHT, lb			
	1,000	2,000	3,000	4,000
	kw-h/mile			
20	0.010	0.020	0.030	0.040
40	0.040	0.080	0.120	0.160
60	0.090	0.180	0.270	0.360
80	0.160	0.320	0.480	0.640

Figure 2d.

ENERGY REQUIREMENTS OF A TYPICAL MEDIUM-SIZE
AMERICAN CAR FOR VARIOUS TYPES OF DRIVING
(kw-h/mile)

Energy use	Urban	Suburban	Turnpike
Tires	0.092	0.092	0.092
Aerodynamic losses	0.011	0.048	0.173
Acceleration	0.086	0.053	0.003
Total	0.189	0.193	0.268

Figure 2e.

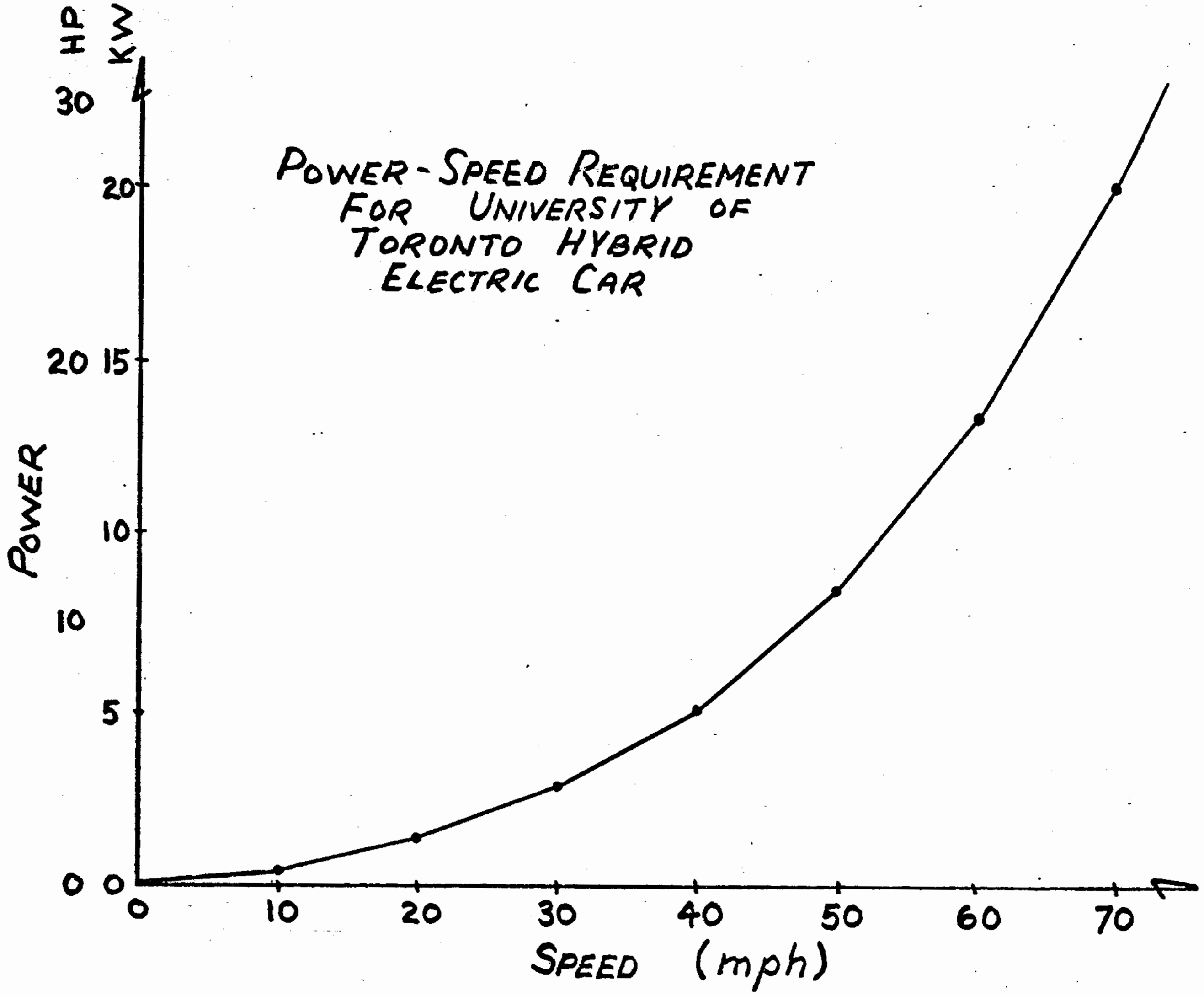


Figure 2f.

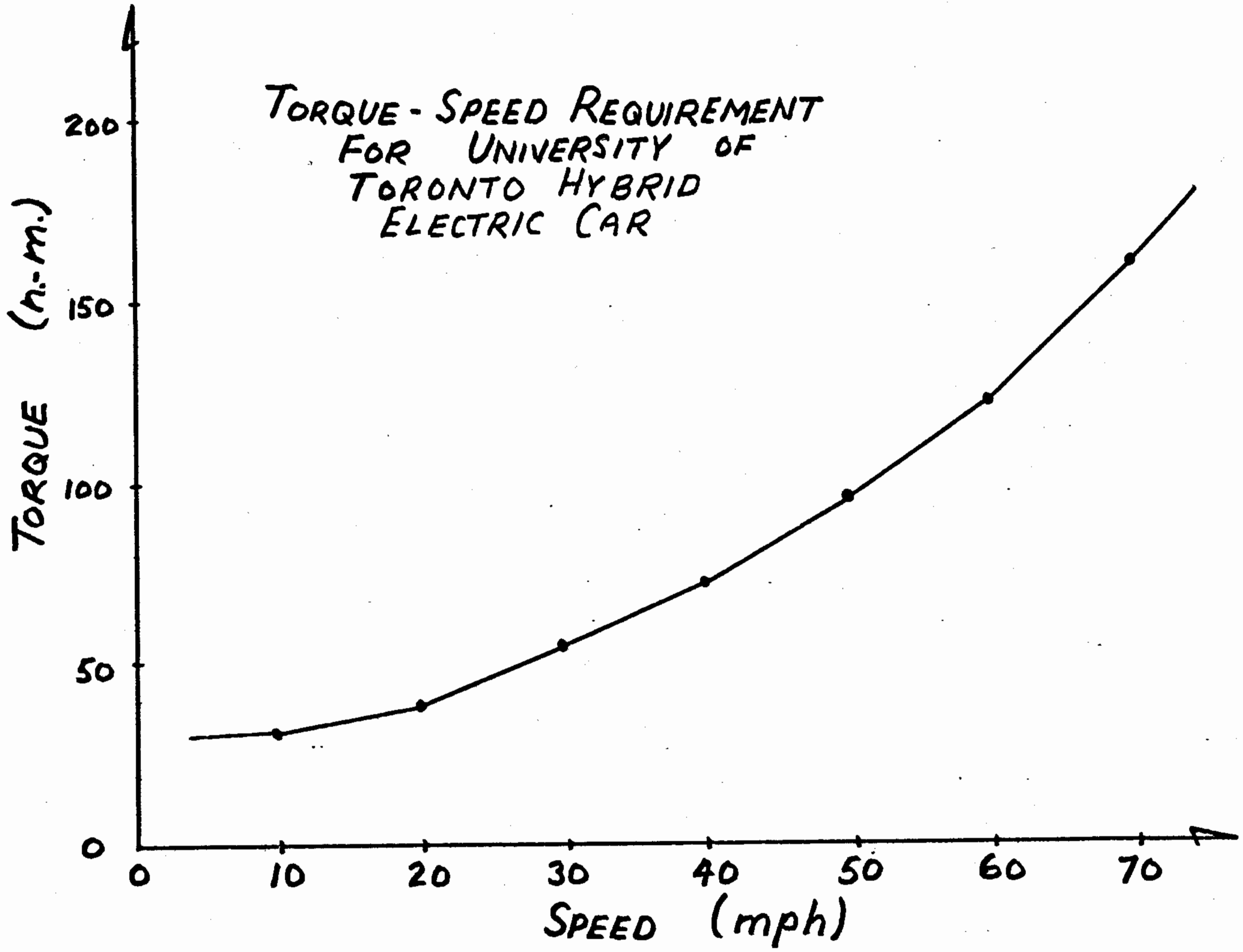

TORQUE - SPEED REQUIREMENT
FOR UNIVERSITY OF
TORONTO HYBRID
ELECTRIC CAR
TORQUE (n.-m.)
200
150
100
50
0
0
10
20
30
40
50
60
70
SPEED (mph)

Figure 2g.

CHAPTER 3

PRODUCTION OF ELECTRICAL ENERGY

The prime mover of the hybrid car will likely be a present day automotive power plant. The characteristics of some conventional automotive engines that could drive the generator of a hybrid are listed in figure 3a. Note that the characteristics of these engines do not vary greatly but since the weight of electric motors and generators varies inversely at the speed at which they turn, it is desirable to choose a prime mover with a relatively high rotational speed.

Figure 3a. PROJECTED CHARACTERISTICS OF PRESENT-DAY AUTOMOTIVE POWERPLANTS UNDER 100 HORSEPOWER

	Gasoline piston engine	Diesel piston engine	Rotary piston engine	Gas turbine
Engine weight per horsepower, lb/hp	3 to 4	4 to 5	2 to 3	1.5 to 2.5
Best thermomechanical efficiency, installed under the hood	0.2 to 0.25	0.3 to 0.35	0.3 to 0.4	0.25
Least fuel consumption at optimum speed, lb/hp-hr	0.4	0.4	0.4	0.35 to 0.45
Relative fuel costs	highest	intermediate	highest	lowest
Lowest number of reciprocating and/or rotating parts between combustion chambers and power pick-off	13 (6 cyl)	13 (6 cyl)	3 (2 rotors)	1
Mass production cost, dollars/hp	2 to 3	2 to 3	2 to 3	3 to 4

Alternating current generators in aircraft to-day operate at top speeds of 8,000 to 10,000 rpm, half to one-third of the turbine's shaft speed of 20,000 to 30,000 rpm. But reduction gears should be avoided in hybrid systems to achieve quietness; and to reduce manufacturing costs, it would be desirable to mount the generator's rotor directly on the power shaft.

In general, we might look to the gas turbine and possibly even the long neglected 2-stroke motor for a primary source of power since both these motors have the qualities of simplicity and high speed.

Mechanical power is converted to electrical by a generator. Because of the varied requirements of controlling the electrical power alternating current generators of the synchronous type will most likely be popular. The output of this generator will be a fixed frequency since the gas motor is turning at fixed speed; the voltage output can be controlled simply by rotor-current control and also these generators are presently available at a reasonable price. Another factor to consider is that synchronous generators can approach 95 per cent efficiency in the size and power rating being discussed here.

CHAPTER 4

STORAGE OF ELECTRICAL ENERGY

Energy for acceleration must be stored in a battery of some sort. In the last few years, interest in electric vehicles has caused much investigation into the properties and possibilities of electric storage batteries. Many new electrodes and electrolytes are being tested and some show great promise. Energy densities of up to twenty times that of conventional lead-acid batteries are available but not without drawbacks. For instance, the sodium-sulphur and lithium-chlorine, with the highest energy densities available so far, have to be worked in the temperature range of 300 degrees C. to 500 degrees C. and 500 degrees C. to 650 degrees C. respectively. A preheating source is therefore necessary and these systems would have to carry a considerable amount of insulation for intermittent use. Also the very active materials present in these exotic storage cells could present dangerous hazards in the event of accident. All this is not to say these cells will never be used; only that much research is necessary before they can be put into use by the consumer on a practical basis. Other systems, such as the silver-zinc cell are much too expensive to be practicaluntil adequate methods of electrode recovery are developed. A chart of reactants and their characteristics is given in figure 4 a.

Storage Batteries – Characteristics

	Working Temp. (°C)	Cell Volts (o/c)	Wh/lb (2-5 hrs)	Life	
				Cycles	Years
L/A	Ambient	2.00	10 - 15	1500	5
Ni/Cd,Fe	"	1.20	10 - 15	2000	7
Ag/Zn	"	1.80/1.50	40 - 50	100	0.5
Na/S	300	1.75	150	?	?
Li/Cl	650	1.80	200	?	?

Figure 4a.

Lead-acid and nickel-iron alkaline storage batteries have to date provided the only source of power sufficiently reliable and durable to meet the commercial requirements of electric vehicles. Typical characteristics of such a batteryare given in table 4 b. In the lead-acid group there are literally dozens of different types and sizes of lead acid batteries on the market - each designed for a specific application. Many of these are being used for propulsion. Four of the most important are flat plate motive power; tubular motive power; golf-cart; and starting, lighting and ignition (SLI) batteries.

Flat Plate Motive Power Cells

For many years flat plate cells have been the standard of the industry for rugged service in industrial truck and mine locomotive applications. Figure 4 c shows the important electrical characteristics of a typical cell.

A battery of six such cells in a steel tray delivers 5.0 kilowatt hours and weighs 576 pounds (8.7 watt-hours per pound). In average service this battery lasts for 6 to 7 years, giving about 2,500 cycles before the capacity drops to 80 per cent of its rated value.

Tubular Plate Motive Power Cells

For certain applications where volume is at a premium, cells with tubular positive plates are widely used. A battery of 18 such cells in a steel tray delivers 20.8 kilowatt-hours and weighs 2,000 pounds (10.7 watt-hours per pound). The service life is somewhat shorter than the flat plate cells but still amounts to 5 to 6 years and about 1800 cycles.

SLI Batteries

These are the batteries used in automobiles. Being relatively low in cost and readily available, SLI batteries are frequently used for experimental electric vehicles. Important electrical characteristics of a common size are given in figure 4 e. The ampere-hour rating of SLI batteries is specified at the 20 hour rate - quite unrealistic for motive power applications. Further, these batteries are designed to deliver large currents for starting and to withstand constant overcharge when the engine is running. These factors combine to make the SLI battery unsuitable for the deep discharges associated with motive power service. However, in a hybrid car, the battery would not be subjected to very deep discharges, and this factor combined with the cost and availability of SLI batteries makes them a very good power source until the more exotic batteries are sufficiently developed to replace them.

Golf Cart Batteries

Golf cart batteries would seem to be the closest approximation to an electric street vehicle lead-acid battery. Two versions of such batteries are on the market. One is based on industrial battery technology and has tubular positive plates. Presumably it will give performance similar to that quoted for tubular plate cells. By far the more common version of the golf cart battery is based on SLI battery design.The principle differences are thicker plates and more effective plate separation. Figure 4 f gives the electrical characteristics of this battery. At the 5 hour rate, the energy density is 14 watt-hours per pound and 1.8 kilowatt-hours per cubic foot. Properly serviced batteries last one to two years.

In the next five to ten years, only the lead-acid battery will be used in significant numbers of electric street vehicles. SLI batteries, which are produced in quantities of 40 million or more per year, are priced to the consumer at about 50 cents per pound. Translated in dollars of initial cost per unit of energy, SLI batteries sell for approximately $35 per kilowatt-hour. Other types of batteries, some made on a large scale to-day, are priced 5 to 50 times the above value. One must conclude that the price structure of the lead acid battery will in the near future lend itself to an attractively priced electric passenger vehicle.

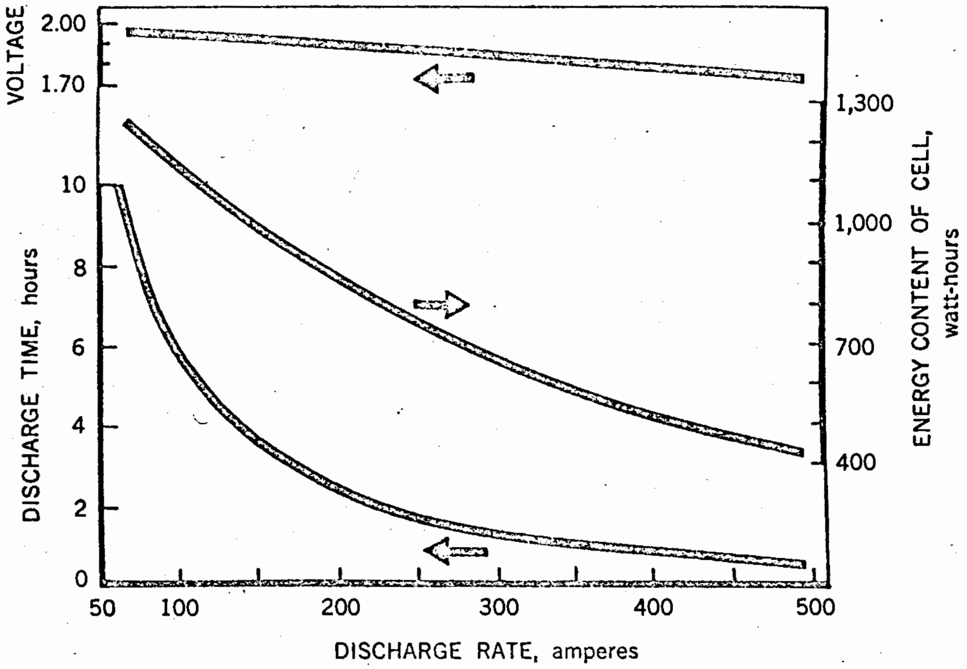


Figure 4b. Discharge characteristics of flat plate industrial battery (GNB type 72X-13, 1.280 SP. GR., 77°F, 81 lb per cell).

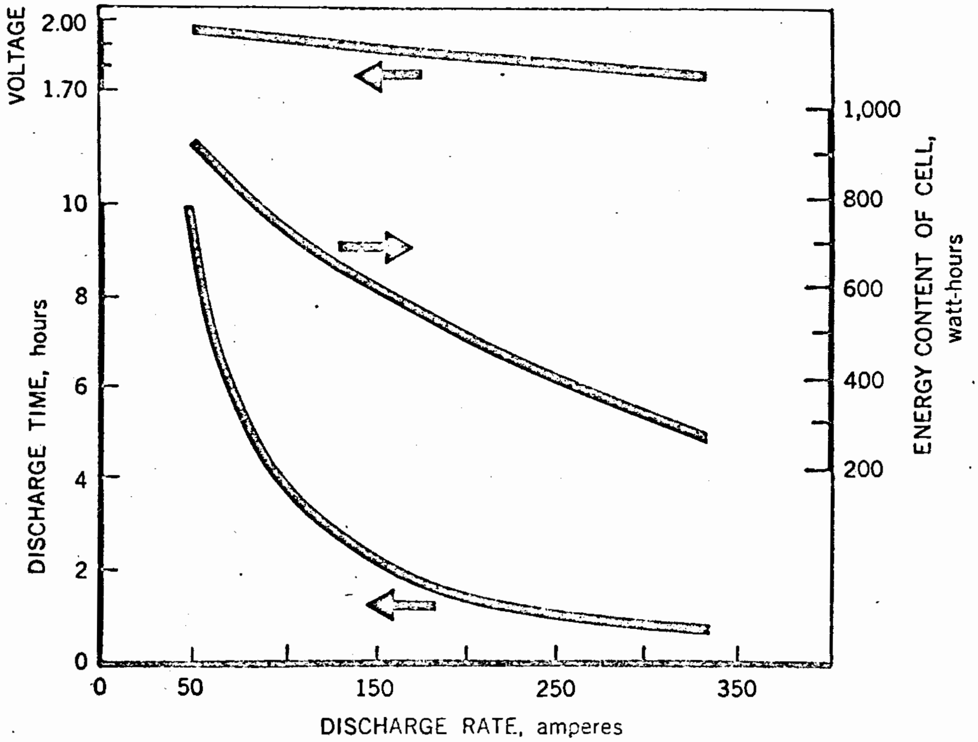


Figure 4c. Discharge characteristics of Tubular-plate industrial battery (GNB type 85T-15, 1.280 SP. GR., 77°F, 85 lb per cell).

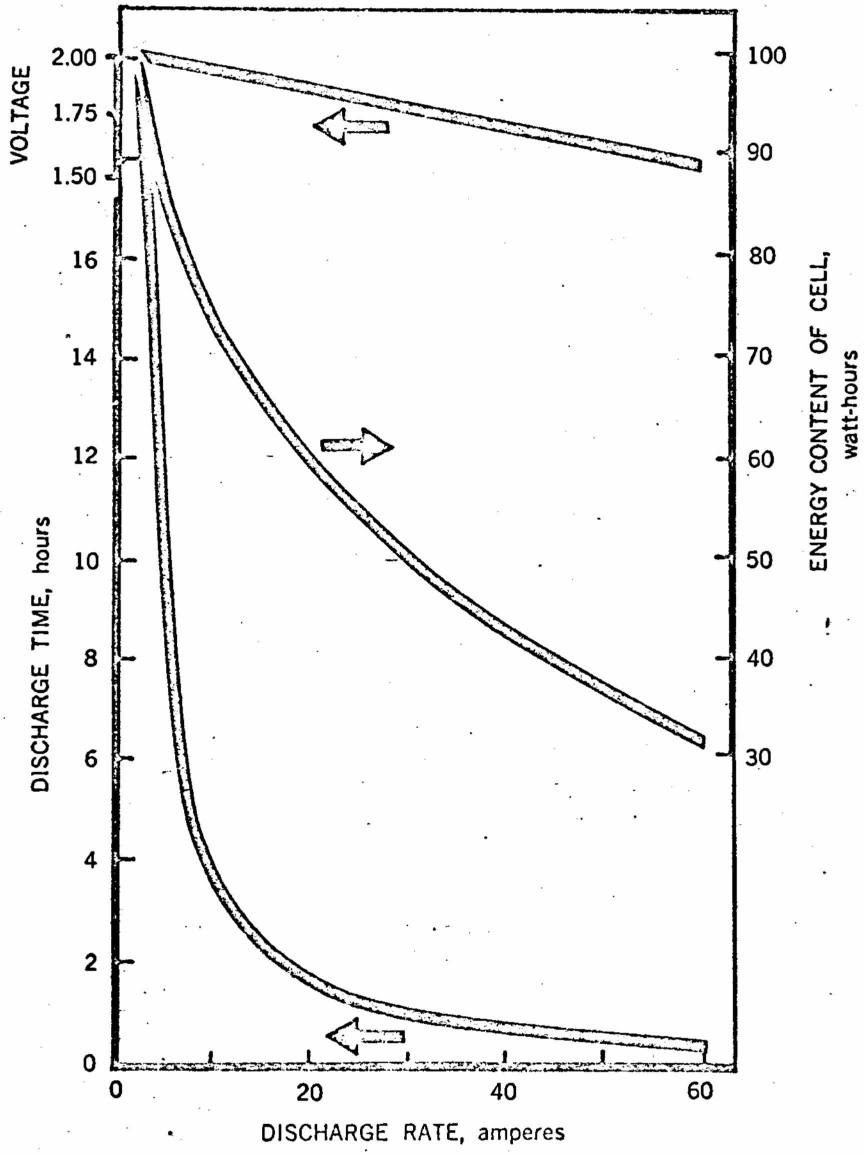


Figure 4d. Discharge characteristics of SLI battery (1.280 SP. GR., 77°F, 42 lb per battery).

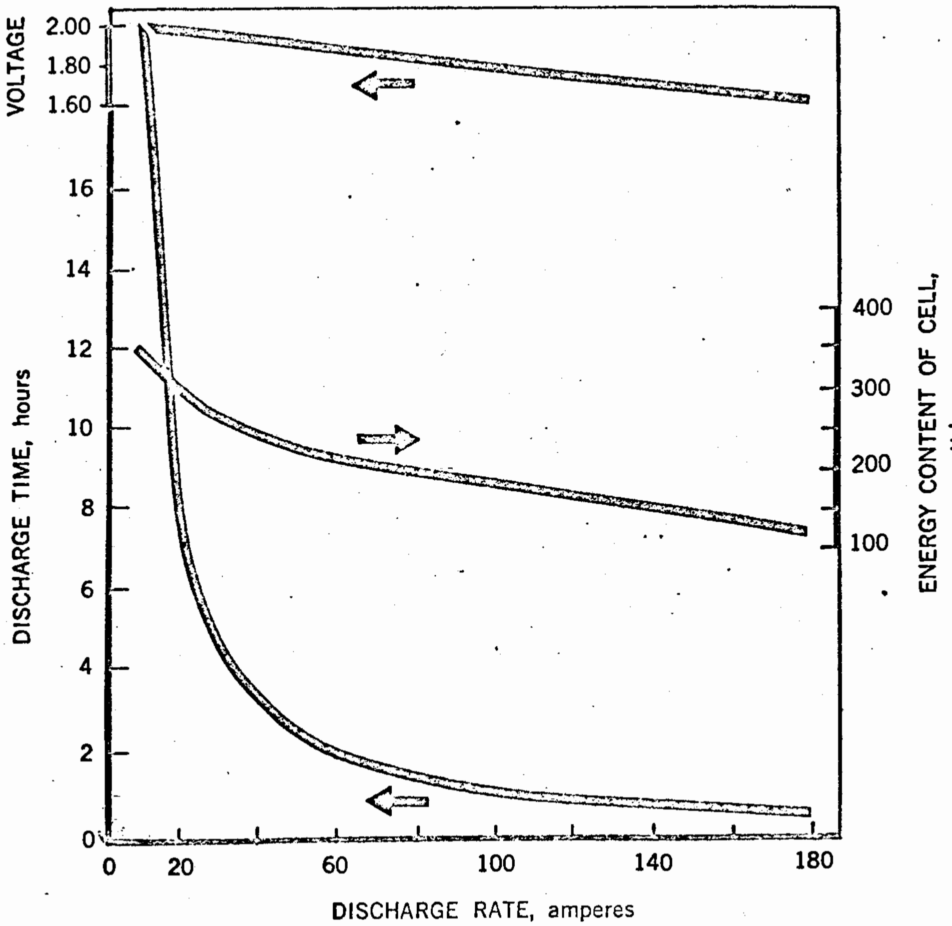


Figure 4e. Discharge characteristics of golf-cart battery (1.280 SP. GR., 77°F, 62 lb per battery).

CHAPTER 5

CONVERSION OF ELECTRICAL TO MECHANICAL ENERGY

The conventional D.C. series motor has been found to have suitable torque-speed characteristics for traction purposes, and most of the small electric commuter cars currently being developed employ one or more. Development of traction motors is primarily aimed at reducing the specific weight, which is somewhat high at 16 lb./h.p. for continuous rating and 8 lb./h.p. for short overload conditions.

Because of the high dead weight of present batteries the efficiency of the motor is of real importance since improvements here will be reflected as substantial weight reductions in the batteries. An improvement of 5% in the efficiency of a small motor normally about 70%, can be achieved with the penalty of an increase of 20% in weight. The weight of batteries will be five times that of the motor, and a 5% reduction in the batteries will more than compensate for a 20% increase in the latter.

Attempts to improve the specific output of variable speed D.C. motors by increasing the rotational speed are limited by poor commutation. Although it is possible to increase the continuously rated output of a motor without a reduction in efficiency by the use of forced cooling, the short term overload condition is not greatly affected since this depends more on the thermal capacity of the machine. For traction purposes, the short term rating, which governs acceleration and hill climbing ability is possibly as important as the continuous rating.

The only alternative to the D.C. motor is the Variable Frequency A.C. Induction Motor. Solid State D.C./A.C. inverters can be built to supply variable frequency and voltage to a squirrel cage induction motor. These motors can be designed to operate at variable frequency provided that the voltage is also varied to maintain constant volts per cycle. In addition, it is possible by varying the invertor voltage in relation to a speed sensitive voltage derived from the motor shaft, to adjust the slip frequency. High starting torque can be obtained as the stator frequency will be low at this time. Possible weight to power ratios including the gear box, invertor and cooling arrangements, could be around 3.5 lb./h.p. at continous rating.

CHAPTER 6

A SUGGESTED SYSTEM

A great many different systems are currently being worked on in different institutions around the world. It would be impossible to say which would be the best system at this stage and also impossible to discuss very many such systems in this paper. The one system presented here is presently being worked on at the University of Toronto under the supervision of Professor S. D. T. Robertson. The project is still in the planning/testing stage and it should be noted that many changes are likely before it sees realization as a test vehicle.

Figure 6 a shows the basic layout of the University of Toronto Hybrid Electric car.

The principle of this system is as follows:
An internal combustion engine running at constant speed and power drives a three phase, 208 volt synchronous generator producing three phase power of approximately 15 k.w. at about 600 Hz. The 600 Hz. power is fed to an all solid-state cycloconverter to produce three phase power at variable voltage and variable frequency. The variable frequency is then used to drive two squirrel cage induction motors each driving one front wheel through a chain transmission. Also tapped onto the 600 Hz. line is a rectifier-inverter bridge and a number of lead-acid storage batteries. When more power is being produced than is needed

(i.e. idling), the excess is rectified and used to charge the batteries. Conversely, when more power is needed than is being produced (i.e. accelerating), the power is drawn from the batteries, inverted to 600 Hz. and fed into the line. There is at present, no provision for regeneration of power during braking or going down hills. This system with its associated controls will be located in the engine compartment of an Austin-Mini Station Wagon.

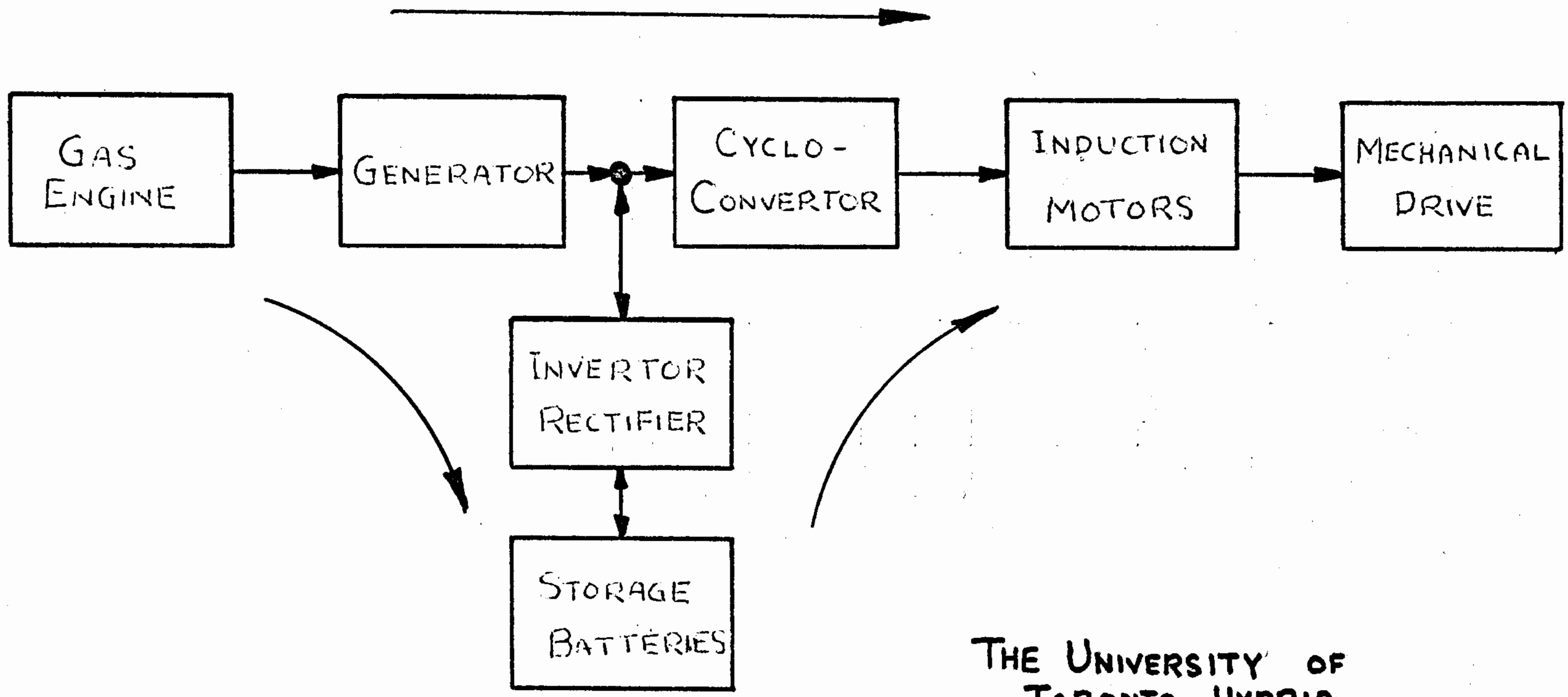
A Suzuki 250 c.c. motorcycle engine is used as the prime mover. Though two-stroke engies are noted for the amount of smoke they produce, it should be noted that this is because of the variety of conditions motorcycles are expected to operate under. This engine, running at 6,000 rpm, and 20 h.p. can be tuned, by using an exhaust extraction system, accurate carburation and ignition, to a high degree of efficiency. The automatic oil supply of this engine can also be adjusted to reduce air pollutants.

The three phase synchronous generator is a Bendix model originally made for the aircraft industry. It is rated at 4,000 rpm, 400 Hz, 208 volts, 55 amps, power factor of 1.0, 20 K.V.A. The generator will be turned at 6,000 rpm instead of its rated 4,000 as the high "factor of safety" specified by the aircraft industry is not really necessary for a test vehicle and the high frequency power supply is necessary to allow sufficient range of speed.

The cycloconverter, as the rectifier and inverter, are all solid-state with a maximum current capability of 300 amps. All bridges will have complete voltage control, the cycloconverter also having a frequency control of 20 to 300 Hz.

The squirrel cage motors are specially built by using the stators of the Bendix synchronous generators and converting the rotors to squirrel cage by removing the wire windings and inserting copper bars.

Storage batteries are of the conventional SLI type, banked in series to provide the voltage necessary. These batteries have the particular advantage of being relatively inexpensive.



THE UNIVERSITY OF
TORONTO HYBRID
ELECTRIC CAR

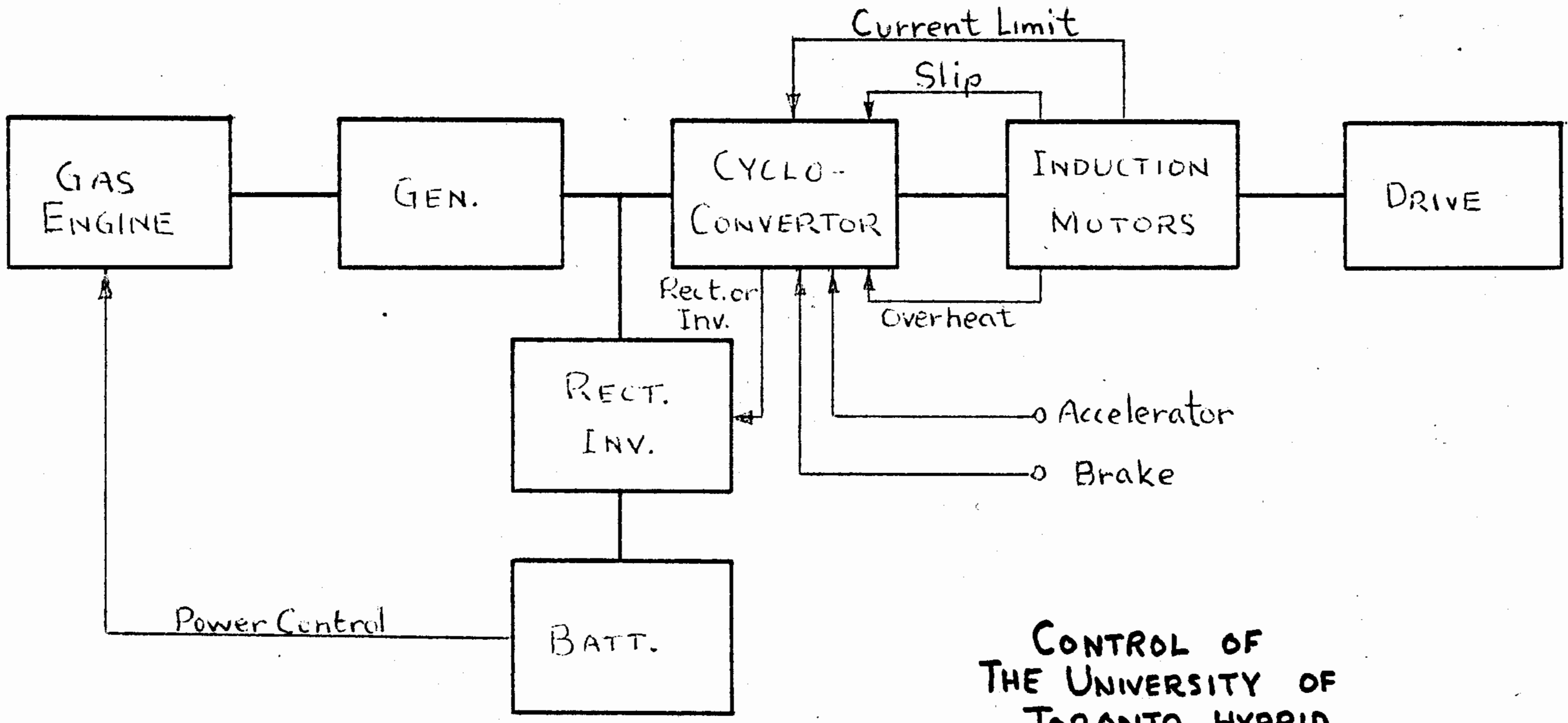
FIGURE 6a.

CHAPTER 7

SYSTEM CONTROL

The control system for the Hybrid Electric Car can be divided into two categories; manual and automatic. The manual control will consist mainly of speed control. Speed control will most likely be accomplished by controlling the firing angle of the cycloconverter bridge. By controlling this angle directly by a foot-pedal, the amount of power being fed to the motors is controlled. The frequency could be manually controlled to control speed but this system would work best at a constant slip frequency so frequency control will have to be automatic. In addition to speed control there will be other manual functions such as starting the gasoline motor (adjusting choke, etc.).

By far the greater part of the control system will be automatic. As mentioned, slip frequency will have to be controlled whether by analog or digital methods. Temperature sensors will have to be provided in the motors, generator and gas engine to cut back the power being transferred by the system if the temperature gets too high. A current sensor will have to limit the current to some maximum value so damage to the S.C.R.'s or motors does not take place. The rectifier-inverter will have to know when to rectify and when to invert (and how much) depending on driving conditions. Also some information about the average state of change of the batteries will have to be fed back to the gas motor to control its average power output. Obviously the gas engine need not produce 20 h.p. when only an average of 10 is needed for city driving. Regenerative braking by cutting back the firing angle in the cycloconverter could put power back into the batteries. The control here would be partly automatic and partly manual since the driver's response to the pedals would have to be compared with the conditions in the system before a degree of regeneration could be established. Figure 7 a shows a simplified layout of the basic control system for the University of Toronto car.



CONTROL OF THE UNIVERSITY OF TORONTO HYBRID ELECTRIC CAR

FIGURE 7a.

CHAPTER 8

PREDICTION OF PERFORMANCE

The performance aspect perhaps most important to the driver is acceleration. How does this Hybrid car compare in "get up and go" to the conventional automobiles? Well, obviously this car is not going to outrun any of Detroit's V8's. Let us take a look at just what kind of acceleration will be available.

For city and suburban driving the average power consumption is about 4.2 K.W. (see chapter 2), therefore, the gas engine will be producing 4.2 K.W. on the average. Let us assume that another 10 K.W. (120 volts, 80 amps) is available from the batteries. This gives us a total power of about 15 K.W. available. The energy required to accelerate to 30 mph for our car would be about 0.045 K.W. - hr.; therefore, the time to accelerate would be given by:

$$T\ (0\text{-}30) = \frac{0.045\ \text{K.W.-hr.}}{15\ \text{K.W.}} \times 3600\ \frac{\text{sec.}}{\text{hr.}}$$

$$= 11 \text{ seconds (approx.)}$$

Now this is obviously quite slow so consider if the car was set up for highway power consumption. The gas motor would now be producing about 15 K.W. and another 10 K.W. from the batteries gives 25 K.W. total. Energy needed to accelerate to 30 mph is still 0.045 K.W.-hr., therefore:

$$T\ (0\text{-}30) = \frac{0.045\ \text{K.W.-hr}}{25\ \text{K.W.}} \times 3600 = 6.5\ \text{sec.}$$

This is still slow by American standards but is quite acceptable. Acceleration to 60 mph can be approximated by:

$$T\ (0\text{-}60) = \frac{0.2\ \text{K.W.-hr.}}{25\ \text{K.W.}} \times 3600 = 29\ \text{secs.}$$

This figure is also quite acceptable. Note here that these calculations are based on the assumption of constant power input to the electric motors. This would mean an infinite starting torque and an infinite starting current. Since the current will have to be limited to some value the acceleration time will be increased somewhat. See figure 8 a.

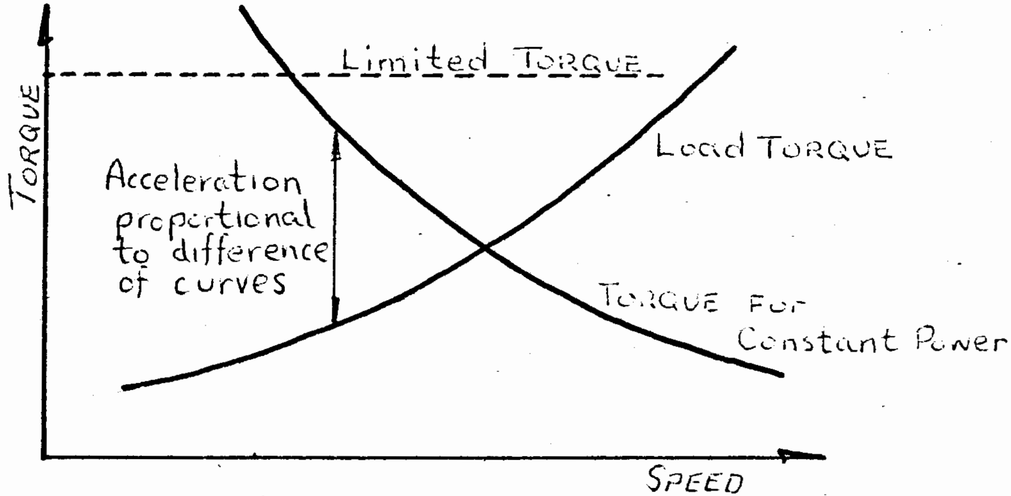


Figure 8a.

Another important factor to consider under performance is just how much this car is going to cost. Obviously if the consumer is going to have to give up some of his power and acceleration, he is going to expect to pay less for his automobile. Unfortunately, figures of costs are not readily available for electric cars of any description. Figure 8 b does however, contain a comparison of capital and running costs of typical Dairy vehicles. Though the vehicles discussed here are not hybrid in nature the costs can be considered comparable (i.e. the cost of the gas engine and generator is offset by the cost of the extra batteries, and charger). Note that the increase in initial cost is offset by the lower cost per mile. Talking in terms of the hybrid car, 100 miles to the gallon of gasoline is not too much to expect.

COMPARISON OF CAPITAL AND RUNNING COSTS OF TYPICAL DAIRY DELIVERY VEHICLES OF 20 CWT PAYLOAD RATING

Vehicle type and year	Electric (*a*), 1952	Electric (*b*), 1965	Electric (*c*), 1965	Petrol (*d*), 1965
Payload, crates	38 metal	45 plastic	45 plastic	45 plastic
Payload, gallons	95	112½	112½	112½
Weekly milage	175	210	231	210
First costs	£ s d	£ s d	£ s d	£ s d
Complete vehicle	790 10 0*	999 10 0	1175 0 0	735 0 0
Battery, 36 cells	309 19 0	369 0 0	369 0 0	—
Charger	94 10 0	123 0 0	123 0 0	—
Total	1194 19 0	1491 10 0	1667 0 0	735 0 0
Standing charges per annum				
Depreciation: vehicle, 10%	75 1 0	94 15 0	112 5 0	136 10 (20%)
battery, 25%	68 16 0	85 10 0	85 10 0	—
charger, 10%	9 9 0	12 6 0	12 6 0	—
Licence	16 5 0	23 5 0	23 5 0	31 10 0
Insurance	11 9 0	18 0 0	18 0 0	24 0 0
Interest	26 2 0	48 0 0	53 15 0	24 10 0
Total p.a.	207 2 0	281 16 0	305 1 0	216 10 0
Running costs per week				
Electricity†	9 10	15 9	15 9	4 7 6 (12 mile/gal)
Tyres	11 2	12 1	13 4	16 9
Repairs and maintenance	11 0	16 7	18 3	1 7 1
Standing charges	3 19 10	5 8 5	5 17 4	4 3 4
Total p.w.	5 11 10	7 12 10	8 4 8	10 14 8
Cost per mile	7·66d	8·70d	8·56d	12·20d
Cost per gallon delivered	2·02d	2·31d	2·50d	3·26d

(*a*) Resistance control with flat-plate battery
(*b*) Resistance control with tubular battery and radial-ply tyres
(*c*) Electronic control with tubular battery and radial-ply tyres

* Price includes £130 purchase tax

† Electricity cost: ¾d./kWh in 1952; 1d./kWh in 1965
Lead cost: £130–170/ton in 1952; £99/ton in 1965 (August)

Figure 8b.

CHAPTER 9

POSSIBLE IMPROVEMENTS

In the last few years great interest in electric vehicles has sprung up. The principle of the electric car has been proven many years ago; now the emphasis is on reducing the losses in these systems to an absolute minimum, since losses have a direct influence on range and running costs. The important thing, is to make these cars practical and practical means cheap. A one per cent loss may add up to $100 over a period of 5 years in wasted battery capital or gasoline.

Literally thousands of new devices and ideas are being tested to-day. During the last decade a number of new winding materials and insulation materials have become available to the motor designer. These can enable machines to work at higher temperatures and to have improved efficiencies. Because of the presently small demand for machines of this type, the advantages of the new materials have not been fully exploited by manufacturers. Most of the materials are expensive and their use in existing designs therefore result in increased prices, but to take full advantage of them, most machines would have to be redesigned. Undoubtedly as production techniques improve, the cost of new materials will decrease and then their advantages will be considered more by designers. Electrographic brushes are now used to a greater extent on D.C. traction motors and have considerably improved life without noticeably affecting the efficiency.

Experimental work is being carried out on the use of new magnetic materials capable of operating at much higher speeds. There is some prospect that high speed machines will become available through the use of semi-conductor devices which may be used to eliminate the commutator and brush gear in the conventional designs. With semi-conductor commutation, speeds of 100,000 rpm are feasible, and control problems may also be eased as a result of these investigations.

Improvements in the size and weight of lead-acid batteries have been achieved in the last 10 years or so through the production of plastics and synthetic materials for separators and other components. Better understanding of the action of active materials and new designs have resulted in better discharge characteristics with somewhat higher average discharge voltages. Improvement in thin sheet separators has increased battery life from 5 to 6 years. Both tubular and flat plate batteries are now using woven plates thus giving them 30 per cent more capacity for a given volume.

There are many many problems yet to be solved before electric vehicles become popular as a consumer product but the advantages of electric vehicles are just beginning to be fully realized.

CHAPTER 10

SUMMARY

It has been shown that the electric vehicle has become more attractive through reduced running costs. Increasing numbers of registered electric road vehicles in Great Britain have verified their acceptance for cheap, reliable transportation. In 1955 about 20,000 were registered and in 1964 the number had risen to over 33,000.

The future is most attractive, the present is encouraging; basic research should be accelerated, commercial development is needed; the long range all-electric vehicle is obscure and problematical, the hybrid electric vehicle only requires enthusiasm and determination.

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