ELECTRIC VEHICLE ENERGY USE SIMULATION MODEL

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ABSTRACT

Electric vehicle propulsion systems are modeled in a driving cycle computer simulation. A very comprehensive vehicle model is used which includes aerodynamic drag, tire rolling resistance, rotational and translational inertia effects, and complete component by component power train efficiencies for varying load and speed. Battery discharge performance is tracked by a fractional-utilization method corrected for short-term prior discharge effects. The Federal Urban Driving Cycle was selected over the less rigorous SAE J227a electric vehicle test cycle to more accurately reproduce actual urban vehicle requirements and predict performance closer to actual vehicle user experience. The computer simulation outputs are used to determine optimized designs for minimum energy usage. An application for a typical suburban passenger vehicle is included.

I. INTRODUCTION

Interest in petroleum fuel conservation and alternative fuel usage has greatly increased in the past decade.

A Department of Energy (DOE) program was established by Public Law 94-313, "Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976." Among other things, it authorized DOE agencies to foster development of electric and hybrid vehicles. Recent government publications (Ref 7) present the results of comparisons through manufacturer-supplied data, user reports, and controlled tests of some 200 different commercially available and experimental electric and hybrid vehicles. These comparisons reveal wide variances in design and energy efficiencies among similar types of vehicles indicating a lack of analysis of many of the designs prior to prototyping or production. In lieu of the increased interest among public and private sectors as well as the observed lack of sophistication among many electric vehicle designs, the prime objective of this effort was to provide an accurate method to simulate electric vehicle systems. The goal was to provide a computer simulation tool which could be used both for new system design as well as evaluation of existing competitive designs. To offer these capabilities, the model and subsequent simulation tool had to be flexible enough to accommodate a wide variety of design options.

Approach

Based upon the lack of correlation between actual performance and early simulation prediction attempts (Ref 7) an early priority of this effort was to carefully select an operating sequence to most realistically portray on-the-road vehicle use. Once determined, road load power requirements could be easily calculated. The dynamic efficiency of each power train component was then individually modeled and assembled together into an interrelated complex vehicle model. Net power requirements to the motor and/or engine could then be obtained. A multi-variable battery model was combined with controller characteristics to determine available power to the motor under any condition. A comparison between this available power and the required power was used to predict the sufficiency of the power supply and/or the performance deviations from the prescribed driving cycle (speed schedule). Further features of the battery model enabled the simulation to track net energy usage and the extent of nominal discharge. Final outputs of the simulation were then the average energy cost per kilometer as well as the amount of battery consumed per cycle, which together with estimated procurement and maintenance costs, can be used as a measure of merit for a selected system.

II. MODELING

A critical feature in any vehicle simulation is the realism of the driving sequence and vehicle model.

Driving Cycle

The SAE J227a cycle is a frequently used driving cycle for testing electric vehicles. However, when used in track tests (Refs 1,2,4,7,8), it generally overpredicts range and underestimates energy usage rate when compared to user experience. A much more rigorous and intricate driving cycle is the Federal Urban Driving Sequence (FUDS, Ref 3), which was developed primarily for dynamometer vehicle emission tests. This 23-minute cycle is the recorded operation of an actual vehicle being driven in an urban area. In spite of its complexity (1371 data points), its realism and ability to provide a base for operating cost comparison with conventional vehicles made the FUDS the logical choice for this simulation.

Road Loads

For travel on roads, the combined vehicle retarding forces can be divided into the rolling resistance, air resistance, and acceleration forces.

Rolling Resistance. The force required to move any vehicle at constant speed without considering aerodynamic or powertrain drag is a function of tire design, inflation pressure, vehicle weight, rolling surface, and vehicle speed (Ref 7).

Aerodynamic Drag. At constant speeds above 60 km/h, air resistance becomes the dominant retarding force for most vehicles (Ref 6).

Acceleration Forces. In realistic urban driving cycles, the inertial resistance to acceleration will, at times, be much larger than either the rolling or air resistance. Besides the translational effects on the vehicle mass, the angular accelerations applied to the rotating masses also produce significant inertial reactions.

Calculation of Road Load Power. For use in the simulation, the calculated resistive forces need to be converted into a required power as a function of time. The input energy is calculated by integrating the required power over each time increment. This work then represents the incremental energy required at the rear wheels to meet the road load demands. Modeling of the vehicle resistance parameters and power train losses is now required to determine the necessary battery output to overcome this road load.

Vehicle Modeling

To prove useful for effective design optimizing, the vehicle model characteristics were resolved into either continuous equations or multidimensional arrays.

Vehicle Mass and Frontal Area. The vehicle mass and frontal area are the primary parameters used in determining road loads. The gross vehicle mass may be considered to be represented by a summation of chassis mass, fixed mass, payload mass, battery mass, and motor mass (to include controls and hybrid engine mass if applicable). While this vehicle mass is used in obtaining rolling resistance, an additional factor of effective rotary mass must be taken into account to predict acceleration loads. The net effect of this rotary mass can be resolved into an equivalent mass located at the rim of the wheels, which can be considered to be a mass correction factor. The frontal area of any vehicle will also, in general, be a function of the vehicle mass.

Axle and Transmission Characteristics. Energy losses in the conventional automotive drive axle occur from both speed-insensitive sources as well as from speed-sensitive sources. Conventional fixed-ratio multi-speed transmissions and many variable-ratio transmissions (Ref 8) have efficiency maps very similar to that of a drive axle.

Motors

The essential requirement of any motor model is to be able to relate output power and current for any operating speed or applied voltage. In series motors, the armature current passes entirely

through the field circuit. The armature current in a shunt field motor does not pass through the field circuit; in fact, for maximum flexibility, the field is often separately excited. For both motors, the electromagnetic power is a function of the field and armature resistance, the applied battery voltage, motor speed, and a motor constant. An efficiency parameter allows the calculation of net output power for a specific motor (Ref 5).

Controllers

Motor controllers must regulate the motor voltage to adjust power output and limit armature current at low speeds. Step-voltage switching controllers employ mechanical relays and high current diodes to adjust the parallel-series battery network. These controllers are simple and efficient. Electronic chopper controls offer continuous voltage control from zero to 95 percent of the battery voltage, and provide maximum operator flexibility (Ref 7).

Batteries

A useful battery model must be able to predict power available and energy remaining at any time during a driving cycle as functions of battery mass, ambient temperature, discharge level, load current, nominal voltage, and loading history.

Energy Capacity. The constant load useful capacity of a battery is a function primarily of discharge rate (Ref 7).

Available Power. The output of a battery is dependent on its internal resistance and is equal to its output voltage times the load current.

Hybrid Power. The major utility of gas-powered hybrid augmentation is to relieve battery drain during high speed cruise. For that reason the hybrid is modeled as being inactive until a designated engagement speed. At that speed the hybrid becomes connected to the drive shaft via some transmission arrangement and is capable of producing any power up to the maximum for its particular operating speed.

This final entry now completes the vehicle model characteristics required to obtain the net input energy necessary to meet the driving cycle road load power demands. It remains for the simulation then to combine all the dynamic characteristics of a particular vehicle system with the driving cycle speed schedule to derive the instantaneous and overall vehicle performance.

III. SIMULATION METHODOLOGY

Figure 1 is a simplified flow chart of the simulation program EVSIM developed during this effort.

The simulation begins by selecting certain "fixed" vehicle and environment parameters. These represents a particular vehicle type and surrounding influences and include such things as payload mass, transmission type, and motor type as well as ambient temperature and fuel costs. Certain "basic" vehicle parameters are also entered at the start. These are parameters such as motor power and battery mass which may be incrementally

Fig 1 EVSIM Flow Chart

changed by the simulation to meet specific performance criteria. Table I lists the specific input parameters grouped by their category.

The driving cycle provides a second-by-second speed schedule. For each time increment, road load forces are calculated and converted to power required at the wheels. Through continuous efficiency equations and/or component efficiency maps, this raw road power is converted to the required motor output power. Calculation of the available motor power depends upon the controller type. For step-type controllers, only discrete power steps are available for any particular motor speed, hence, an exact match with the required power at any increment is unlikely. The power step closest to the power required is selected and then an iterative procedure accomplished by adjusting the interval's terminal speed until the power required does match the available power. For continuous controllers, EVSIM assumes a perfect match between required and available power until the maximum available power is insufficient to meet the demands. Then, as with the step-controller an iterative procedure determines the actual speed attained at the end of each interval. For systems using a gas-engined parallel hybrid, the simulation assumes that the continuously controllable hybrid power is used only to match the total available power with that required.

Once the actual vehicle speed and motor power for each time increment have been resolved, the fraction of battery discharge is calculated. This entire process is repeated until the cycle is complete or until the vehicle fails to meet a

TABLE I
EVSIM Input Parameters

	FIXED	BASIC
Vehicle Parameters	Drag coefficient	Frontal area
	Payload mass	
	Fixed mass	
	Rolling radius	
	Rolling coefficient	
	Axle ratio	
Vehicle Parameters	Transmission type	
	(Multi-ratio) gear ratios	
	shift speeds	
	(CVT) efficiency data	
	Motor type	Rated power
	base speed	Armature resistance
	efficiency data	Field resistance
	maximum power ratio	k* value
		Maximum current
	Controller type (Step voltage)	Step source impedance
Other Parameters		voltage fractions
	Nominal battery voltage	Battery mass
	Hybrid coupling efficiency	
	speed ratio	
	engagement speed	
	operating gear	
	Ambient temperature	
	Electric energy cost	
	Petroleum fuel cost	
	Speed schedule	
	Program option	

performance criterion.

An option is available (design versus evaluation) which allows the simulation to calculate requirements when certain deficiencies in a given design cause undesirable performance. If the basic vehicle is insufficiently powered, an excessive speed deviation from the driving cycle schedule will cause EVSIM to increase the rated power and associated parameters until the schedule can be achieved. On the other hand, if lack of energy storage is apparent from an excessive discharge fraction, EVSIM can increase the battery mass. Naturally, both of these parameter adjustments are interrelated and typically one will require the other.

When the cycle has been successfully completed (a simulated 23-minutes for the FUDS), the final outputs of EVSIM include the total motor energy used, the total deceleration energy available at the motor (for regeneration), the percent of battery discharge at cycle completion, the average electrical cost per kilometer, and the final vehicle parameters if adjustments were made. The power cost is based on an average charger efficiency of 85 percent (Ref 7) combined with the battery model's 70 percent efficiency to produce a net 60 percent energy transfer from AC power at the charger to DC power out of the batteries. If a parallel hybrid system is simulated, EVSIM also recalls the total engine energy used along with the average petroleum fuel cost per kilometer.

Simulation Application

Figure 2 is a sample output of the developed electric vehicle simulation program, EVSIM. This sample output demonstrates EVSIM's evaluation mode. The vehicle modeled has the configuration of the test-bed vehicle design. It represents a series motor/gasoline engine parallel hybrid. The transmission is a four-speed conventional gear ratio model (although only the first three gears are used during hybrid augmentation). The controller is a five-step battery-switching system that uses a combination of relays and high power diodes to control the motor supply voltage. The selected portions of the complete FUDS cycle included in Fig 3 indicate the extent of computed data available for each increment of the chosen driving cycle. The final entries of Fig 3 show the overall energy recap that is computed at the end of each completed simulation cycle.

VI. SUMMARY

The EVSIM program does provide a useful evaluation and design tool for electric vehicle systems. The program has the flexibility to simulate both electric and electric/hybrid configurations using series or shunt motors, step-voltage or continuous controllers, and gear-ratio or continuously variable transmissions for any general shape and size of vehicle. Any specific driving cycle may be used to simulate the vehicle operation. Finally, EVSIM has the ability to internally modify a basic input vehicle to provide improved performance to meet required standards.

ELECTRIC VEHICLE SIMULATION

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VEHICLE CONSTANTS ARE:
  DRAG COEFFICIENT= .42
  FRONTAL AREA= 1.80 SQUARE METERS
  PAYLOAD MASS=270. KILOGRAMS
  FIXED MASS=325.

ENVIRONMENTAL CONSTANTS ARE:
  AMBIENT TEMPERATURE= 27. CELSIUS
  ELECTRIC ENERGY COST= $.050 PER KWHR
  PETROLEUM FUEL COST= $.35 PER LITER

POWER REDUCTION VARIABLES ARE:
  TIRE ROLLING RADIUS= .343 METERS
  ROLLING COEFFICIENT= .0105
  AXLE RATIO= 4.13
  NUMBER FORWARD GEARS= 4
  MAXIMUM VELOCITY=112. KM/HR

FIXED SPEED TRANSMISSION VARIABLES ARE:
  MOTOR UPSHIFT SPEED=1500. RPM
  MOTOR DOWNSHIFT SPEED= 500. RPM
  GEAR RATIOS= 3.800
               2.040
               1.260
               .880

MOTOR VARIABLES ARE:
  MOTOR TYPE= SERIES
  RATED POWER= 6.0 KW
  BASE SPEED=3200. RPM
  MAX ARMATURE CURRENT= 400. AMPS

5 STEP CONTROLLER VARIABLES ARE:
  VOLTAGE FRACTION= .167 SOURCE IMPEDANCE= .0030 OHMS
                  .333          .004
                  .500          .009
                  .667          .018
                  1.000          .036

BATTERY VARIABLES ARE:
  NOMINAL VOLTAGE= 72.
  BATTERY MASS= 350.

7KW SERIES HYBRID VARIABLES ARE:
  HYBRID/MOTOR SPEED RATIO= 1.950
  COUPLING EFFICIENCY= 96.5%
  ENGAGEMENT SPEED= 45.0KM/HR
  TRANSMISSION POSITION= 3 GEAR

SYSTEM EVALUATION OPTION SELECTED

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Fig. 2 EVSIM Sample Output

A test vehicle has been constructed with the aid of EVSIM. This vehicle is currently being used to validate and refine the models in EVSIM.

EVSIM was written in FORTRAN, and executed on a CDC CYBER 175. The program required less than 45 thousand octal words and 3.5 execution seconds for the FUDS cycle.

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TIME (SEC)	VELD-SCH (KMP/HR)	VELD-ACT (KMP/HR)	DEVIATION (KMP/HR)	F-ROLL (INT)	F-AIR (INT)	F-ACCEL (INT)	INPUT-POWER (KTR) (HYB)	GEAR SELECT	SHAFT-RPM (NTR) (HYB)	CONTROLLER STEP/FIELD	MTN VOLTS	ARM AMPS	BAT DISCHARGE (%)
1	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
2	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
3	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
4	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
5	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
6	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
7	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
8	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
9	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
10	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
11	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
12	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
13	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
14	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
15	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
16	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
17	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
18	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
19	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
20	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	0.0000
21	4.2	6.1	1.3	131.	0.	3493.	3.5 0.0	1	368.	0.2	-1	23.5	201.
22	5.5	9.0	-4	131.	2.	1666.	4.4 0.0	1	914.	0.3	-1	35.2	153.
23	13.2	13.6	-2	131.	4.	2652.	10.1 0.0	1	1372.	0.5	-1	66.1	187.
24	18.4	19.0	.6	131.	9.	2295.	12.0 0.0	2	1073.	0.5	-1	64.9	229.
25	22.9	27.5	-4	131.	15.	1458.	10.1 0.0	2	1365.	0.5	-1	66.1	188.
26	27.1	26.6	-4	131.	21.	1587.	12.8 0.0	3	987.	0.5	-1	64.3	245.
27	27.7	27.5	-2	131.	25.	222.	3.9 0.0	3	1087.	0.3	-1	35.4	124.
28	29.0	29.0	-0	131.	27.	575.	6.2 0.0	3	1135.	0.4	-1	45.9	154.
29	31.7	31.7	-1.5	132.	32.	1037.	10.9 0.0	3	1219.	0.5	-1	65.4	206.
30	34.4	34.0	-8	132.	37.	982.	10.4 0.0	3	1320.	0.5	-1	65.9	193.
31	35.9	36.0	.1	132.	42.	782.	10.0 0.0	3	1407.	0.5	-1	64.3	183.
32	36.0	36.3	.3	132.	45.	115.	3.2 0.0	3	1454.	0.3	-1	36.0	96.
33	35.4	35.4	0.0	132.	44.	-353.	-1.6 0.0	3	1442.	0.0	-1	0.0	0.
34	34.4	34.4	0.0	132.	42.	-368.	-1.7 0.0	3	1404.	0.0	-1	0.0	0.
35	33.5	33.5	0.0	132.	40.	-369.	-1.7 0.0	3	1365.	0.0	-1	0.0	0.
36	32.7	32.7	0.0	132.	39.	-307.	-1.1 0.0	3	1330.	0.0	-1	0.0	0.
37	31.7	31.7	0.0	132.	38.	-368.	-1.6 0.0	3	1274.	0.0	-1	0.0	0.
38	27.2	27.2	0.0	132.	30.	-1719.	-11.9 0.0	3	1185.	0.0	-1	0.0	0.
39	23.9	23.9	0.0	131.	22.	-1209.	-7.5 0.0	3	1027.	0.0	-1	0.0	0.
40	23.9	24.2	.3	131.	20.	123.	2.0 0.0	3	966.	0.2	-1	24.2	94.
41	24.4	24.5	.1	131.	20.	115.	2.0 0.0	3	978.	0.2	-1	24.2	93.
42	24.4	24.8	-1	131.	21.	108.	2.0 0.0	3	990.	0.2	-1	24.2	92.
43	25.6	25.8	.2	131.	22.	391.	4.1 0.0	3	1016.	0.3	-1	35.4	131.
44	27.4	27.5	.1	131.	24.	660.	6.5 0.0	3	1071.	0.4	-1	45.8	162.
45	30.6	30.5	-1	132.	29.	1151.	11.4 0.0	3	1166.	0.5	-1	65.4	214.
46	33.8	33.0	-8	132.	35.	944.	10.6 0.0	3	1276.	0.5	-1	65.7	198.
47	36.4	35.1	-1.2	132.	40.	821.	10.1 0.0	3	1369.	0.5	-1	64.1	187.
48	36.7	37.0	.3	132.	45.	736.	9.8 0.0	3	1451.	0.5	-1	66.5	179.
49	36.4	36.4	0.0	132.	46.	-261.	-7.7 0.0	3	1475.	0.0	-1	0.0	0.
50	36.2	36.2	-0	132.	45.	-69.	1.3 0.0	3	1458.	0.2	-1	24.2	65.
51	34.1	34.1	0.0	132.	42.	-790.	-5.6 0.0	3	1413.	0.0	-1	0.0	0.

TIME (SEC)	VELD-SCH (KMP/HR)	VELD-ACT (KMP/HR)	DEVIATION (KMP/HR)	F-ROLL (INT)	F-AIR (INT)	F-ACCEL (INT)	INPUT-POWER (KTR) (HYB)	GEAR SELECT	SHAFT-RPM (NTR) (HYB)	CONTROLLER STEP/FIELD	MTN VOLTS	ARM AMPS	BAT DISCHARGE (%)
1335	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	12.8190
1336	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	12.8172
1337	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.	-1	0.0	12.8154
1338	2.4	3.3	.9	131.	0.	1913.	1.1 0.0	1	201.	0.1	-1	11.8	152.
1339	7.7	8.1	.5	131.	1.	2779.	5.3 0.0	1	695.	0.3	-1	35.0	180.
1340	13.0	13.3	.3	131.	4.	2940.	10.5 0.0	1	1297.	0.5	-1	66.0	196.
1341	18.3	18.9	.6	131.	9.	2372.	12.3 0.0	2	1075.	0.5	-1	65.0	233.
1342	21.1	20.7	-4	131.	13.	780.	5.6 0.0	2	1300.	0.4	-1	46.4	138.
1343	24.2	23.0	-12	131.	17.	1288.	9.8 0.0	2	1461.	0.5	-1	66.7	178.
1344	26.9	27.6	.7	131.	23.	1401.	12.4 0.0	3	1032.	0.5	-1	64.8	237.
1345	29.3	29.1	-2	132.	28.	568.	6.2 0.0	3	1140.	0.4	-1	46.1	154.
1346	31.2	31.0	0.2	132.	32.	1043.	10.9 0.0	3	1224.	0.5	-1	65.6	206.
1347	32.5	32.3	0.2	132.	35.	185.	3.5 0.0	3	1209.	0.3	-1	35.7	107.
1348	34.1	34.6	.5	132.	38.	867.	10.3 0.0	3	1344.	0.5	-1	66.2	191.
1349	35.1	34.9	-2	132.	41.	131.	3.3 0.0	3	1376.	0.3	-1	36.0	100.
1350	35.4	35.2	0.2	132.	42.	123.	3.3 0.0	3	1409.	0.3	-1	36.0	99.
1351	35.9	36.0	.1	132.	44.	314.	5.2 0.0	3	1432.	0.4	-1	46.6	127.
1352	35.2	35.2	0.0	132.	44.	-307.	-1.1 0.0	3	1433.	0.0	-1	0.0	0.
1353	34.6	34.6	0.0	132.	42.	-246.	-6.6 0.0	3	1404.	0.0	-1	0.0	0.
1354	33.8	33.8	0.0	132.	40.	-307.	-1.1 0.0	3	1375.	0.0	-1	0.0	0.
1355	32.8	32.8	0.0	132.	38.	-368.	-1.6 0.0	3	1339.	0.0	-1	0.0	0.
1356	32.0	32.0	0.0	132.	36.	-307.	-1.1 0.0	3	1304.	0.0	-1	0.0	0.
1357	31.4	31.4	0.0	132.	35.	-246.	-6.6 0.0	3	1275.	0.0	-1	0.0	0.
1358	29.6	29.6	0.0	132.	32.	-675.	-4.0 0.0	3	1227.	0.0	-1	0.0	0.
1359	28.0	28.0	0.0	132.	29.	-614.	-3.4 0.0	3	1159.	0.0	-1	0.0	0.
1360	26.4	26.4	0.0	131.	25.	-614.	-3.2 0.0	3	1095.	0.0	-1	0.0	0.
1361	24.8	24.8	0.0	131.	23.	-614.	-3.0 0.0	3	1030.	0.0	-1	0.0	0.
1362	22.4	22.4	0.0	131.	19.	-921.	-4.7 0.0	3	950.	0.0	-1	0.0	0.
1363	17.6	17.6	0.0	131.	14.	-1842.	-8.8 0.0	3	805.	0.0	-1	0.0	0.
1364	12.8	12.8	0.0	131.	8.	-1842.	-6.7 0.0	3	612.	0.0	-1	0.0	0.
1365	8.3	8.3	0.0	131.	4.	-1898.	-4.7 0.0	2	695.	0.0	-1	0.0	0.
1366	4.0	4.0	0.0	131.	1.	-2491.	-3.5 0.0	1	748.	0.0	-1	0.0	0.
1367	0.0	0.0	0.0	131.	0.	-2306.	-1.1 0.0	1	243.	0.0	-1	0.0	0.
1368	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.0	-1	0.0	0.
1369	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.0	-1	0.0	0.
1370	0.0	0.0	0.0	131.	0.	0.	0.0 0.0	1	0.	0.0	-1	0.0	0.

TOTAL CYCLE TIME (MIN) = 22.8167
 TOTAL CYCLE DISTANCE (KMS) = 11.6328
 TOTAL MOTOR INPUT ENERGY (KWH-HR) = 1.2554
 TOTAL ENGINE INPUT ENERGY (KWH-HR) = .1755
 TOTAL REGENERATION ENERGY AVAILABLE (KWH-HR) = -.5320
 BATTERY DISCHARGE AT END OF CYCLE (%) = 13.1092
 AVG CYCLE ELECTRICAL COST (\$/KWH) = .0090
 AVG PETROLEUM FUEL COST (\$/KWH) = .0030

Fig. 3 EVSIM Output (FUDS)