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Electric-Car Range Extension through Hybrid Modification

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Summary

Electric Car Range Extension through Hybrid Modification

A gasohol powered generator set has been installed on a 1210 pound electrically powered Citicar. A power supply has been designed to convert the alternating current of the generator to run the car at a level of 36 vdc maximum. This is less than the 48 vdc used by the Citicar battery pack but which greatly exceeds the ratings on the 3.5 hp General Electric motor. Tests were done to see the minimum stepping voltage to give smooth acceleration and this was found to be 18 vdc. Tests with the generator-power supply set showed a level path consumption of 35-40 mpg. Switching between the genrator and battery supplies is accomplished manually. The conclusion is that hybridization can be accomplished fairly reasonably but much needs to be done on the development of the electric car itself and particularly battery systems.

Electric Car Range Extension through Hybrid Modification

The purpose of this project was to design and develop a hybrid electrical car that is still economical. The design would concentrate on substitution of a combustion powered source which could be used interchangeably with the existing battery supply. Initially, it was planned that the combustion engine would be alcohol powered; however, with the current Federal Administration's removal of many of the incentives for alcohol plant construction, it became necessary to modify the scope of the project to use gasohol or regular unleaded gasoline as pure ethanol fuel is not likely to be available on any reliable basis in the next several years as was thought to be the case when the project was first conceived.

An electric car was lent to the project for conversion by J.B. Akin, a private electrical contractor, with the understanding that the modified car would be his after completion of the research. The car is manufactured by Citicar. It sells for about \$5500. The car is 95 inches long; 55 inches wide; and 58 inches high. It weighs 1210 pounds unloaded and has a load capacity of 500 pounds.

Experimentation on the project was centered around two thrusts--examining the feasibility of smoothing the acceleration characteristic of the vehicle through a finer voltage gradation and on using a generator to demonstrate that the vehicle could be run in a hybrid mode. Finally an assessment was made to determine the economic feasibility of commercial production of some hybridization kit. All three tasks were completed on the revised schedule that was approved by the Department of Energy; however, the principal findings of the research program point to very real problems with at least this make of electric vehicle in terms of any commercial future although the concept of a hybrid mode of operation was successfully demonstrated.

The Citicar manual describing the vehicle performance and specifications showed a number of discrepancies in terms of the all-important electrical system and it became evident that design parameters and approaches could not reliably be pursued without further, more detailed information. The motor bore a General Electric Company designation of 5BC49JB320. General Electric was contacted and kindly provided a detailed specification sheet which revealed a great deal of information that was nowhere mentioned by Citicar. General Electric also informed us that this motor had been removed from service because of burnout problems in their equipment although there was one electric car company that continued its use. Upon receipt of these specifications it became evident that several problems had to be evaluated and compensated appropriately. The principal problems were that the motor had a maximum on-time of

45 minutes at the nominal load rating of 5.76 lb.ft. torque and 4 minutes at 16 lb.ft. maximum torque. Operation was also recommended at 36 vdc rather than the 48 vdc maximum used by Citicar. It was therefore decided that it would not be appropriate to endanger the entire drive system of Mr. Akin's car by carrying out the research at the maximum level used by Citicar themselves as they were already on a marginal portion of any design criteria suggested by General Electric. Thus, all design was centered around 36 vdc operation rather than the 48 vdc that would exactly replicate the Citicar maximum operating point. It was also decided to limit the fuel capacity to that furnished with the 3500 watt generator which provides about one hour maximum run time so that again the research would not place the operator with the temptation of exceeding the General Electric specifications. These specifications are included as Appendix A of this report.

The next task undertaken was evaluation on the effect of using a finer gradation on the voltage control of the motor. The two level contactor set on the Citicar was used to simulate the multiple level contactor control. Both six and twelve volt step increments were tried and results with the system were not satisfactory. It became readily apparent that the torque curve of the General Electric motor and accompanying Citicar transmission was such that no gain in performance would occur with less than an eighteen volt shift in voltage.

Effort was next devoted to design considerations for the most economical method for operating the vehicle from a commercially available generator set. Several different generation approaches were evaluated prior to purchase of the Sears set actually used to obtain the research data. One attractive alternative that was considered was the use of automotive type generators driven by a small four cycle engine. The structure of the Citicar was such and the project budget likewise that it did not seem feasible to get these mounted, connected mechanically and running in a way that would actually produce experimental data. The possibility of using rapid charge of the battery system through a generator set was also evaluated with the conclusion that battery life would be dramatically shortened and the range of the vehicle would not be extended theoretically to the goal of greater than two hundred miles (with the General Electric motor ratings cited above this car could not be safely operated in excess of fifty miles no matter what energy system is used). With the self-imposed design criteria of thirty six volt maximum test voltage and ready conversion availability between gasohol operation and electric recharge operation, a fullwave bridge transformer power supply was developed around a Sears 220 vac 3500 watt alternator. With an estimated system conversion efficiency of about ninety percent this yields a thirty six volt motor current of eighty five amperes which yields a motor operating point almost exactly on the operating point recommended by General Electric. The transformer itself was rated at 100 amperes at 36 volts. The lower drive voltage

was obtained from the bridge using the transformer center tap. The diodes chosen were rated at 400 piv and 150 amperes. Filtering of the 36 volt supply was accomplished with 200,000 uf at 50 vdc and 100,000 uf at 50 vdc for the 18 volt supply. Two 1 ohm limiting resistors rated at 1500 watts were also provided in the circuit for initial tests so that neither the Citicar motor contactor system nor the power supply would be in any danger. The power supply was initially tested using the 1 ohm resistors in parallel with forced air cooling. The generator bridge set had no difficulty of 1 hour sustained operation with the 72 ampere dummy load. Following this evaluation the system was installed on the rear of the car as shown in Figures 1 and 2. The rear window of the Citicar was removed and the system was installed on a wooden support cradle which held the entire generator, transformer, diode, capacitor assembly. Because the resistors were only a safety and test precaution they were simply taped to the car roof for ease in removal and for maximal cooling exposure. The entire system weighed more than originally anticipated totalling approximately 200 pounds which represents the equivalent of another passenger. That leaves a rated weight carrying capacity of 300 pounds which should accommodate two passengers of average size without overloading the vehicle. Also, no interference with passenger space occurred with this mounting. The four cycle engine is, however, very noisy and for permanent use some acoustical baffling would be highly desirable. Within the conservative constraint of 36 vdc operation to protect the car, results were very encouraging. Measure of gasohol utilized versus mileage obtained indicates that the hybrid operation yields a performance of 35-40 mpg. With an equivalently rated electric motor in terms of weight, power, and efficiency, but having a multi-hour maximum on-time a 5-6 gallon generator feed tank will extend the vehicle range to greater than 200 miles combined gas/electric operation. A serious disappointment in this test was the lack of needed torque to handle grades and hills where the motor is run by the Citicar design far in excess of its ratings. In this research hybridization a large knife switch was used to move from gasohol/generator power to battery power. With more time, funds, and a dedicated car that did not require consideration of the owner's future use, a switching arrangement could automatically move the batteries in for high torque requirements and switch back to gasohol/generator for cruising using the same design. Another alternative in a car that is dedicated entirely to research would be to use a 48 vdc generator derived voltage and run the car a full 5-6 hours or to motor burnout, whichever first occurs. As can be seen from the motor specifications the thermal sensor does not offer burnout protection because of rapid rotor temperature rise.

In conclusion, hybridization of the electric car has been demonstrated with gasohol performance that gives economy consistent with other internal combustion powered sub-compact vehicles. Due to unexpected motor ratings that are grossly exceeded by the electric car manufacturer and the requirement

that the vehicle be returned to its owner in operable form, a conservative posture was taken in the demonstration. The hybridization process as accomplished required parts that even in quantity prices will exceed \$1200.00. At this point in the country's energy development it is questionable as to whether it is worthwhile to invest a total of nearly \$7000.00 in a hybrid vehicle of limited use--it is, however, important to be able to demonstrate that such can be successfully accomplished at a cost for parts of about twenty per cent of the original vehicle price. It is apparent that the technology for hybridization is actually ahead of the electric car development itself and research is badly needed on battery weight reduction, recycleability, and maintenance. Additional hybrid research could be valuable on switching techniques and on generator evaluation.

Figure 1. Electric car with generator/power supply mounted.

Figure 2. Close-up of generator/power supply assembly.

Appendix A

Technical drawing of a component with two views. The right view shows a component with a 4-terminal connection. Dimensions and callouts include:

- 5/16-18 UNC-2A (14)
- 4 TERMINALS
- 2.5
- 1.5

3800 RPM MIN. SPEED AT 9.76 LB. FT. RATED TORQUE FOR CON. MOT.
WITH 36 V AT MOTOR TERMINALS AND MOTOR AT 25 °C.

- 1 MEAT TREAT SURFACE HARDNESS 50-55 Rc. TOTAL CASE SHALL EXTEND .375-.24 BELOW MINOR DIA. OF SPLINE AND SHALL EXTEND AT LEAST INTO SEAL SEAT DIAMETER WITH A .330 MIN DEPTH AT A (DET) THRU IN ED-LANCED VIEW.
- 2 ECCENTRICITY OF PITCH DIAMETER (WITH INDICATOR MOUNTED STATIONARY RELATIVE TO MOTOR CASE) SHALL NOT EXCEED .001 IN W/ SHAFT IS ROTATED IN MOTOR GEARINGS. MEASUREMENT TO BE TAKEN ON 90 OF CHAIN.
- 3 ECCENTRICITY OF THIS DIAMETER WITH INDICATOR MOUNTED STATIONARY WITH RESPECT TO SHAFT, SHALL NOT EXCEED .004 TIR.
- 4 WOBBLE OF THIS SURFACE, WITH INDICATOR MOUNTED STATIONARY RELATIVE TO SHAFT, SHALL NOT EXCEED .004 TIR MEASURED AT 6.25 DIA.
- 5 SHAFT SEAL 135HARDNESS (MIN GRIND) .001-.0008 STYLE STD OR EQUIVALENT. BUNA-B SPRING LOADED LIP MAX .007 LEAK @17°C MAX RPM 5000.
- 6 BEARING PRELOAD AND SPACING UNIFORMS. END PLAY .002" MAX AT 51 LB. MIN. FULL .013 MIN., .072 MAX AT 240 LB. MIN. MOVEMENT MUST RECOVER WITH IN .30SEC
- 7 WHEN MOTOR IS APPLIED, BRASS HOLES MUST BE LOCATED IN A "DOWN" POSITION.
- 8 3/8-16-UNC-18 (4 HOLES) .75 MIN. FULL T-THREAD. THESE HOLES SHALL FIT 4 TIME THING-A RASSET 0.5/50S DIAM. AND 4 PINS .2913 DIAM. LOCATED C/T-4 BASIC HOLE POSITIONS.
- 14 TORQUE NUTS TO 50-70 LB. IN. MOTOR MAY BE DAMAGED IF NUTS ARE TORQUED TOO HIGH.
- 15 ACCESS COVER/ FOR BRUSH INSPECTION MUST BE REPLACED SECURELY TO PREVENT FIRE.
- 16 CLAMP BOLTS & POLE PIECE SCREWS TO BE TORQUED TO 30/110 INCH LB.

9. NORMALLY CLOSED THERMAL SENSOR TEXAS INSTRUMENTS CAT. NO. 91000-A8 NOMINAL RATING - OPENING TEMPERATURE 155-195°C. CLOSING TEMPERATURE 113-86°C.
WINDING WILL BE HOTTER THAN THERMAL SENSOR, PARTICULARLY AT OVERLOAD CONDITIONS WITH RAPID HEATING.
WINDING LIFE RATED ON RESISTIVE LOAD - 10000 CYCLES BREAK AND MAKE AT 24 VOLTS MAX OR 3 AMPS MAX OR C.
THERMAL SENSOR DOES NOT PROTECT MOTOR AGAINST DAMAGE.
10. MOTOR SPEED SHOULD NOT BE ALLOWED TO EXCEED 5000 RPM.
11. MOTOR HAS CLASS F (155°C TYPICAL) INSULATION SYSTEM. OPERATION ABOVE THIS TEMPERATURE WILL SHORTEN LIFE AND MAY DAMAGE MOTOR. ACTION TEMPERATURE SHOULD NOT BE ALLOWED TO EXCEED 200°C.
12. BRUSHES AND COMMUTATOR SHOULD BE INSPECTED PERIODICALLY. BRUSHES SHOULD BE REPLACED IF SHORT OR BROKEN. SEE INSTRUCTION BOOK GFB-365 FOR DETAILS.
13. FOR NOMINAL MOTOR - MAKE ON TIME 60 MINUTES AT FL TORQUE 15.2 LB.-FT., STARTING FROM 25°C AMBIENT.
FOR OVERHAUL MOTOR - MAKE ON 6 MINUTES AT 16.0 LB.-FT. TORQUE, STARTING WITH MOTOR AT MAX AMBIENT OF 55°C

<u>PARTS</u>		<u>QTY</u>	<u>UNIT</u>	<u>PRICE</u>	GENERAL ELECTRIC GPM WPA 2 MORT WAYNE <h1 style="text-align: center;">OUTLINE</h1> <div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> CAPTCSG388 CODE IDENT NO. <div style="float: right; font-size: 1.5em; font-weight: bold;">326D154</div> <div style="clear: both;"></div> </div>
<u>ITEM</u>	<u>DESCRIPTION</u>	<u>QTY</u>	<u>UNIT</u>	<u>PRICE</u>	
1	12 INCHES	1	EA		
2	12 INCHES	10	EA		
3					
4					
		<u>TOTAL</u>	<u>QTY</u>	<u>PRICE</u>	