NATIONAL TRANSPORT RESEARCH CENTRE

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# BATTERY POWERED ELECTRIC VEHICLE

NTRC-103

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# CHAPTER - 1

## INTRODUCTION

Because of recent energy crisis and expected oil shortage in the foreseeable future, coupled with the fact that the transport sector is almost 100% dependent on oil almost throughout the world (specially the road transport sector) concerted efforts are being made through out the developed world to develop an electric transport system so as to reduce the extreme dependence of the road transport sector on oil, which is produced by only a few oil producing and exporting countries, and thus provide a dependable 'fall back' position in the event of an oil crises.

In the search for a dependable fall back position, several types of Electric Vehicles (Overhead, Battery operated and hybrid) covering a fairly large cross-section of vehicles have been designed and developed. Of the above three types, notwithstanding its extreme limitations, the battery powered EV does possess the flexibility of the conventional IC engine in that it carries its power unit with it and is thus 'self-contained'. The study is however confined to an examination of the prospects of a Battery powered EV.

In the developed countries the primary emphasis of research in the field of electric energy for transport is on developing an economically viable passenger car, to reduce the extreme dependence on gasoline. During the process of refining the crude oil to meet the requirements of gasoline, large amount of heavier distillates such as High Speed Diesel Oil, etc. are also produced. But consumption of the H.S.D.O. in transport in these countries is well below the supply as only 15-20% of the vehicle population are trucks and buses which use H.S.D.O. The shortage of fuel for transport in these countries is in fact shortage of gasoline. Therefore, efforts are primarily directed towards relieving the dependence on 'gasoline' consuming vehicles. Other important consideration is the pollution problem largely attributable to I.C. engines and make the EV particularly attractive for off-road type of applications as in plants, railway stations, airports, etc. and for urban use only due to extreme range limitation.

On the other hand the problem of the developing countries are opposite. For example in Pakistan our requirements of crude oil is largely determined by the H.S.D.O. being consumed by the commercial vehicles like trucks and buses, etc. The amount of gasoline thus generated in the refining process is sufficient to meet the requirements of cars, etc. Hence our requirement would therefore be to find an alternative source of energy for HSD.

The Report has been split into various Chapters. With this Chapter (no. 1) as the 'Introduction', Chapter-2 quantifies the POL dependency of the transport sector in Pakistan and proves that it is basically the requirement of HSD in the transport sector which largely determine the overall POL import bill. Chapter-3 briefly describes the various types of Electric Vehicles and discusses in somewhat greater detail the Battery Powered Electric Vehicle. The current status of Battery Powered Electric vehicles has been reviewed alongwith an analysis of the type of vehicles produced/ developed, and the operating characteristics to quantify the potential of such vehicles. The market potential of Battery powered Electric Vehicles like any other product is dependent on its cost effectiveness and 'task suitability'. While the EVs are characterized by their smooth and quiet ride characteristics, their extreme limitation is on account of the very short range available with the battery system, which limits their freedom of use. It is precisely on account of this reason that presently the production of such vehicles is predominantly for 'off-road' applications like fork-lift trucks, golf carts, in-plant load/personnel carriers, etc. For on road applications, these are largely used as limited range Urban delivery vehicles which involve multi-stops and cover only modest daily mileage of upto about 40 kms and have long and regular idle periods suitable for battery recharge like the 'milk floats' in UK. Urban buses have been designed and developed but on a very restricted scale. Also as urban cars, their possibility as second or third cars (in multi-car-ownership) is considered to have some potential because second or third cars are often used only for local journeys and an alternative car would be available for the occasional long journey.

The most critical component in a Battery Powered Electric Vehicle is the storage Battery itself and Chapter-4 discusses the various types of batteries with emphasis on the commercially available batteries, the maintenance requirements, the essential precautions for the safe and efficient use of the batteries and the serious bottlenecks associated with their use specially in the context of Electric Vehicles. The major technological challenge is the development of a cheap, dependable, long life, light weight, maintenance free, high power and high energy density battery with minimal 'charging time' coupled with the development of 'cheap sources' of electricity for charging the batteries and a network of 'refuelling' stations available at convenient places. Each one of these factors are extremely important and demanding and need to be overcome for achieving the feasibility and comparability with the presently available 'conventional' internal combustion road vehicles. The battery industry in Pakistan has been briefly discussed at the end of the Chapter.

Chapter-5 very briefly describes the Battery Powered Electric Bus Project undertaken by the National Transport Research Centre in collaboration with the National Institute of Power and the Punjab Road Transport Corporation. Since the design details of the d.c. series motor and the associated speed control circuits, etc. would form a separate Report to be prepared by the National Institute of Power, only a very brief mention has been made in this Report.

Although the limitations of a battery operated vehicle are too obvious, specially in our context (where the battery industry do not even cater for providing SLI-Starter, Lighting and Ignition)type of batteries, the project for the design and development of an Electric Bus was undertaken with a view to at least develop the 'Vehicular parts' (mainly the D.C. Series Motor and speed control systems, etc.) indigenously (not done before) and depending on the economics of the 'Power Source' (battery or overhead electric supply) can be used advantageously at the time of need. Thus while the vehicular parts have been successfully developed by the NIP, the project has been held in abeyance because of the extreme limitations on the battery system. Of all the vehicles, the 'Electric Bus' was chosen as it is the extreme dependence on HSD in the road transport sector as mentioned earlier, which dictates our oil import bill and therefore a suitable replacement for HSD operated vehicles (mainly buses, trucks, etc.) would be helpful in effectively checking the demand of oil in the road transport sector.

Chapter-6 discusses the critical factors - the battery and the infrastructural requirements. Most of the current literature/work on EVs is biased in favour of the Electric Vehicles and in a number of cases does not clearly bring out the critical/crucial factors involved specially the infrastructural requirements or are based on assumed/desired performance characteristics of the battery system which in a number of cases precludes the chances of realistic assessment of the actually available potential.

Chapter-7 concludes that the EV potential for 'on road' type of vehicles given the present state of commercially available batteries is indeed quite limited. The current Electric Vehicles do not provide any comparative advantage as regards Energy Conservation. It is, however, recommended that despite the current limitations, the EV Technology (not necessarily battery powered) would have to provide a dependable 'fall back' position in the event of a total oil crises and it is with that end in view that the developments in EV Technology are fully monitored.

# CHAPTER - 2

## POL DEPENDENCY OF THE TRANSPORT SECTOR - NEED FOR ALTERNATIVE ENERGY SOURCES

Transport Sector is almost entirely dependent on POL, most of which has to be imported from aborad involving huge capital outlays. The overall position has been discussed in the following paragraphs to quanitfy the present situation :

### Overall Energy Situation in Pakistan :

Energy issue has occupied a dominant position in the economic planning of Pakistan for a long-time. Being an energy deficient country, it has borne the brunt of oil crises starting in the early seventies. Despite appreciable increase in local production of Oil, oil import alone accounts for about 19% of the total imports and about 35% of total exports (1985-86).[1]

Although the energy consumption has been steadily rising at a rapid pace, the per capita commercial energy consumption in Pakistan is only 0.16 TOE per year or approximately 225W per person as compared to the average per capita consumption of 2KW, 3-6KW and 12KW for the world, Western Europe and U.S. respectively.[2]

### Energy Supplies :

The total commercial energy supply during the year 1985-86 was 17.9 million TOE against 13.33 million TOE during 1980-81.[3] An annual compound growth rate of 6.1%

was recorded over the period 1980-81 to 1985-86. The share of oil has increased due to Government's policy to replace the use of gas by oil in some sectors from 36.7 percent in 1980-81 to 40.2 percent in 1985-86 with a corresponding decrease in the share of gas from 41.6 percent to 35.0 percent over the same period. The contribution of petroleum as a whole has, however, not changed during the last 20 years and remained at about 75% of the total energy supply in the country. Table 2.1 compares the Energy Supply position by source for the year 1980-81, 1984-85 and 1985-86.

The present position with respect to various sources of energy is detailed below :-

CRUDE OIL : The domestic production of crude oil has increased from 35,399 barrels per day in June, 1985 to 40,878 barrels per day in June, 1986. The production of oil in the last week of November, 1986 was 47,567 barrels per day from 13 oil fields. The oil is refined in three refineries having a total refining capacity of 130,000 barrels of oil per day. The total production during the first 3 years of the 6th Five Year Plan is 28.76 million barrels which has surpassed the total target of 17.89 million barrels fixed for the same period and is about 60% more than the target. During the year 1985-86, 32.91% of total crude oil supply (indigenous + imported crude) in the country was met from indigenous sources against 23.5% in 1984-85 and 12.9% in 1983-84.

GAS : The average production of gas in the year 1985-86 was 1042 MMcft per day against 991 MMcft per day in 1984-85 and 947 MMcft per day in 1983-84. Out of the 19 gas fields discovered so far, only three fields are on production.

## TABLE : 2.1 ENERGY SUPPLIES*

UNIT : MTOE

| Source | 1980 - 81 | | 1984 - 85 | | 1985 - 86 | | A.C.G.R. | |
|---|---|---|---|---|---|---|---|---|
| | MTOE | Percent Share | MTOE | Percent Share | MTOE | Percent Share | 1980-81-1984-85 | 1980-81-1985-86 |
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
| Oil | 4.891 | 36.7 | 6.933 | 40.8 | 7.188 | 40.2 | 9.1 | 8.0 |
| Gas | 5.546 | 41.6 | 6.021 | 35.4 | 6.260 | 35.0 | 2.1 | 2.5 |
| Coal | 0.706 | 5.3 | 1.001 | 5.9 | .985 | 05.5 | 9.1 | 6.9 |
| Hydel | 2.109 | 15.8 | 2.908 | 17.1 | 3.278 | 18.3 | 8.4 | 9.2 |
| Nuclear | 0.033 | 0.3 | 0.071 | 4.1 | 0.104 | 0.6 | 21.1 | 25.9 |
| LPG | 0.042 | 0.3 | 0.0752 | 4.1 | 0.0751 | 0.4 | 15.7 | 12.3 |
| Total | 13.327 | 100 | 17.009 | 100 | 17.891* | 100 | 6.3 | 6.1 |

* Excluding feed stock, auxilliaries, imported coal, etc.

Source : Energy Year Book, 1986, Directorate General of New and Renewable Energy Resources (DGNRER), Islamabad (Ref: 3)

ELECTRICITY : The total installed capacity of electricity generation is 6,299 MW out of which Hydel Power is 2,898 MW and Thermal Power in 3,263 MW. Generation and Consumption of electricity by all the sources in 1985-86 was recorded at 25,638 GWH and 19,665 GWH against 23,003 GWH and 17,584 GWH in 1984-85 showing an incrase of 11.5% and 11.8% respectively. The share of hydel in the generation remained maximum as usual at about 53.8 percent.

COAL : Current use of coal is restricted to brick-kiln industry which accounts for more than 97% of the total production. Roughly about 26,000 tonnes of coal per annum is consumed by two 7.5 MW coal fired power units at Quetta. The rest is used for domestic heating, etc.

Energy Consumption by Sector :

The Sectoral distribution of energy in MTOE based on the information for the years 1980-81 and 1985-86 is presented in Table 2.2.

TABLE : 2.2 ENERGY CONSUMPTION BY SECTOR

Unit : MTOE

| Sector | 1980 - 81 | | 1985 - 86 | | ACGR 1980-81 to 1985-86 |
|---|---|---|---|---|---|
| | MTOE | % Share | MTOE | % Share | |
| 1. | 2. | 3. | 4. | 5. | 6. |
| Domestic | 1.625 | 12.5 | 3.083 | 17.2 | 13.7 |
| Commercial | 0.414 | 3.2 | 0.578 | 3.2 | 6.9 |
| Industrial | 4.092 | 31.4 | 5.214 | 29.1 | 5.0 |
| Agriculture | 0.693 | 5.5 | 0.866 | 4.8 | 4.6 |
| Transport | 2.582 | 19.8 | 3.397 | 19.0 | 5.6 |
| Power | 2.153 | 16.5 | 2.953 | 16.5 | 6.5 |
| Fertilizer | 0.530 | 4.1 | 0.727 | 4.1 | 6.5 |
| Other Govt. | 0.934 | 7.2 | 1.072 | 6.0 | 2.8 |
| Total :- | 13.023 | 100 | 17.890* | 100 | 6.6 |

* Normalized w.r.t. Table 2.1.

It will be seen from this table that the transport sector consumes about 18-20 percent of the total energy consumed and has registered an annual increase of 5.7 percent over the period 1980-81 to 1985-86.

## Sectoral Share of Different Types of Fuels :

The Sectoral share of different types of fuels may be seen in Table 2.3.

TABLE : 2.3 SECTORAL SHARE OF DIFFERENT TYPES OF FUELS - (1985-86)

(Percent)

| Description | Domestic | Commercial | Industry | Agriculture | Transport | Power | Ferti. | Other Govt. |
|---|---|---|---|---|---|---|---|---|
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
| Petroleum | 26.9 | 3.1 | 19.6 | 24.9 | 99.75 | 31.2 | - | 56.2 |
| Gas | 30.4 | 37.8 | 31.7 | - | - | 68.5 | 100.0 | - |
| Electricity | 42.5 | 59.1 | 31.3 | 75.1 | 0.25 | - | - | 43.2 |
| Coal | 0.2 | - | 17.4 | - | - | 0.3 | - | 0.5 |
| Total : | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

It is evident from Table 2.3 that the transport sector is almost 100 percent dependent on petroleum.

## Energy Consumption in Transport :

Energy consumption in transport amounted to 3.234 MTOE during 1985-86 which accounted for nearly 18% of the total energy consumed (Table 2.2). The primary source of energy for transport is oil with a negligible portion by coal and electricity (in Railways only) as detailed in Table 2.4.

TABLE 2.4 ENERGY CONSUMPTION IN TRANSPORT SECTOR

UNIT : MTOE

| Description | 1980 - 81 | | 1985 - 86 | | ACGR 1981 - 86 |
|---|---|---|---|---|---|
| | MTOE | % Share | MTOE | % Share | |
| 1. | 2. | 3. | 4. | 5. | 6. |
| Aviation | 0.206 | 7.8 | 0.218 | 6.4 | 1.1 |
| MS | 0.471 | 18.2 | 0.658 | 19.4 | 6.9 |
| HOBC | 0.121 | 4.7 | 0.186 | 5.5 | 9.0 |
| HSD | 1.706 | 66.1 | 2.236 | 65.8 | 5.6 |
| LDO | 0.003 | 0.1 | 0.004 | 0.1 | 4.4 |
| FO | 0.064 | 2.5 | 0.087 | 2.6 | 6.4 |
| Electricity | 0.011 | 0.4 | 0.009 | 0.3 | -3.9 |
| Total : | 2.582 | 100 | 3.397 | 100 | 5.7 |

It may be seen that the largest proportion of energy (about 66% percent of the total energy consumed) is provided by the HSD.

Local Production of Crude, Refining Capacity and Imports

Although the local production of crude oil has increased from 0.477 million metric tons in 1980-81 to 1.926 million metric tons (ACGR 32.2%), it has been roughly estimated that the entire processing of the locally produced crude oil would meet transport sector requirements of HOBC, HSD, MS & AV fuel to the extent of only about 16%, 19%, 31% and 71% respectively. However there would be surplus as regards the LDO and FO.

At present Pakistan imports crude oil and POL products as per details in Table 2.5. While the value has decreased from 1,590 million US $ in 1980-81 to 1,035 million US $ in 1985-86, the quantity in term of MTOE has increased from 5.788 to 6.341 registering an increase of about 1.5 percent per annum.

Table : 2.5 Import of Crude and POL Products*

(Million US $)

| Description | 1980-81 MTOE | 1980-81 Value | 1985-86 MTOE | 1985-86 Value |
|---|---|---|---|---|
| Crude | 4.177 | 995 | 3.925 | 602 |
| POL Products | | | | |
| - Aviation Fuel | 0.002 | 1 | 0.004 | 2 |
| - HOBC | 0.072 | 30 | 0.091 | 16 |
| - S.K. | 0.389 | 155 | 0.507 | 110 |
| - H.S.D. | 1.148 | 409 | 1.295 | 241 |
| - F.O. | - | - | 0.519 | 64 |
| Sub-Total : | 1.611 | 595 | 2.416 | 433 |
| Total :- | 5.788 | 1,590 | 6.341 | 1,035 |

* Excluding non-energy lubes.

It may be pointed out that even with the processing of the entire imported crude oil as well at the local refineries. the shortfall is of the order of 39% and 47% for HSD and HOBC as per details in Table 2.6. The two products, have therefore to be imported even for meeting the requirements of the transport sector.

TABLE : 2.5 - COMPARISON OF PRODUCTION OF PETROLEUM MIX PRODUCTS BY LOCAL REFINERIES AND TRANSPORT SECTOR REQUIREMENTS

| S. No. | Product | 1980 - 81 | | | 1985 - 86 | | |
|---|---|---|---|---|---|---|---|
| | | Local Refineries | Transport Sector | Surplus(+)/ Deficit(-) | Local Refineries | Transport Sector | Surplus(+)/ Deficit(-) |
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. |
| 1. | Av. F | 0.540 | 0.206 | + 0.334 | 0.495 | 0.218 | + 0.277 |
| 2. | MS | 0.506 | 0.471 | + 0.035 | 0.664 | 0.658 | + 0.006 |
| 3. | HOBC | 0.040 | 0.121 | - 0.081 | 0.098 | 0.186 | - 0.088 |
| 4. | HSD | 0.971 | 1.706 | - 0.735 | 1.360 | 2.236 | - 0.876 |
| 5. | LDO | 0.176 | 0.003 | - 0.173 | 0.227 | 0.004 | + 0.223 |
| 6. | FO | 1.454 | 0.064 | - 0.390 | 1.502 | 0.087 | + 1.415 |
| | Total :- | 3.687 | 2.571 | | 4.346 | 3.389 | |

It is thus evident from the preceding that the POL requirements for transport are heavily tilted towards HSD for most of heavy road vehicles and railways, followed by Gasoline for light road vehicles and aviation fuel for air-crafts. It is the extreme dependence on HSD which dictates our oil import bill and therefore a suitable replacement for HSD operated vehicles (mainly buses, trucks, etc.) would be helpful in effectively checking the demand for oil in the road transport sector.

# CHAPTER - 3

## THE ELECTRIC VEHICLE

An Electric Vehicle can be defined as a vehicle in which the driving traction is provided an electric motor.

There are different types of electric vehicles and the difference primarily emerges on account of the mode/nature of energy supply to the electric motor. Electric Vehicles may be classified into three general types[4] as :

(a) Overhead Electric Vehicles;
(b) Battery Operated Electric Vehicles; and
(c) Hybrid Vehicle

These are briefly described below :

(a) Overhead Electric Vehicles :These vehicles draw power from an overhead or ground level power supply and are essentially 'tracked vehicles'. Examples include electric trains, tramcars, trolley buses, etc. All such vehicles are used for public transportation. It may be of interest to note that while within the railway system there is a progressive move towards electrification, the opposite trend has occurred for road vehicles with many tramcars and trolley buses having been replaced by diesel buses.

(b) Battery Operated Electric Vehicles : These vehicles use secondary batteries for providing the requisite power and are 'self-contained' with a freedom to roam at will. However, until now their usefulness has been restricted by the limited range provided by the traction batttery. For this reason their principal application has been in situations where short range is not a serious handicap and where freedom from exhaust and/or noise pollution is of marked benefit e.g. as small tugs, tractors or fork-lift trucks for use in airports, mines, hospitals, warehouses, factories etc. In the United States the electric golf cart is used extensively. These are all 'off the road' applications and hardly count as serious 'transport'. Road use has been limited to milk delivery vehicles (electric 'milk floats' in the UK), a few city centre buses and to experimental urban goods and postal delivery vans. Many electric cars have been designed and built in small numbers, but so far no production line has operated successfully for more than a short while.

(c) Hybrid Vehicles : Hybrid Vehicles are relatively recent in origin. They consist of a traction battery used in conjunction with a second motive power source, either mains electricity, an internal combustion engine or a flywheel energy storage system. With the mains battery hybrid an auxiliary battery is provided to allow limited range operation away from the power cable. Thus trains may run on branch lines or into sidings which are not electrified, while trolley buses may penetrate suburban residential communities away from the cable so as to provide more convenient service to passengers.

Since the Study primarily relates to a battery powered electric vehicle, the main discussion that follows is confined to it.

## Battery Powered Electric Vehicles

The essential components of a battery powered electric vehicle[5] are the D.C. motor (usually d.c.series wound), the controller and the battery as per schematic diagram, shown in Fig. 3.1.

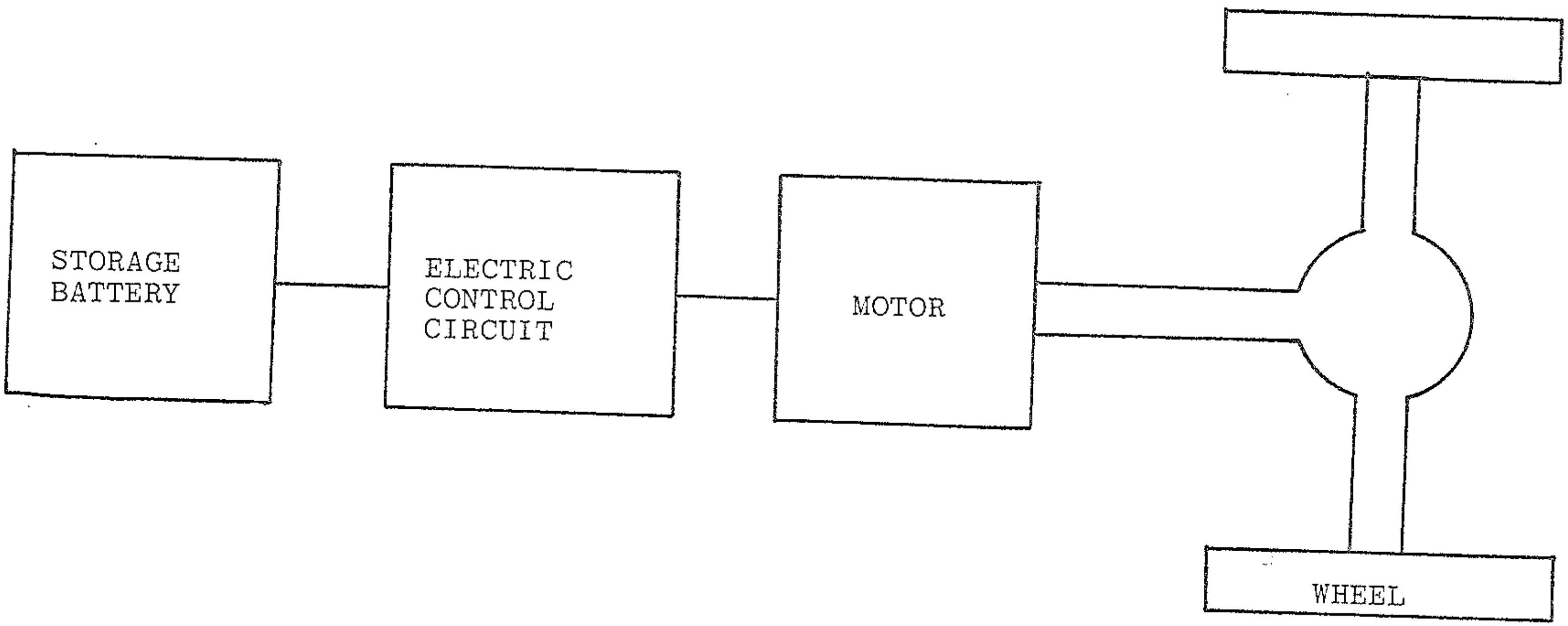



Fig. 3.1 Schematic diagram of the Drive System used in an Battery Powered Electric Vehicle

## Current Status of Battery Operated Electric Vehicles

In order to assess the developments made in the design and development of battery operated electric vehicles, the production of such vehicles has been reviewed alongwith the description of their salient characteristics. Electric Vehicles produced include various types like bikes, passenger cars, golf carts, buses, forklift trucks, vans, etc.

The production figures of such electric vehicles for the years 1975-77 are given for the major manufacturing countries in Table 3.1.[4] It can be seen from these figures that although in terms of the maximum impact of oil crises during this period, the production figures do not discern a consistent pattern and there seems to be a general downward trend in EV production during this period. Except for increase in fork lift trucks in Japan, there is no real indication of substantial growth in any of the markets. It may be seen from Table 3.1 that during 1977 :

(1) 48,700 fork lift trucks constituting 52.5 percent of the total EV production ranked the highest followed by 22,700 golf carts (24.5 percent), 9,200 in-plant load carriers (9.9 percent), 3,870 bikes (4.2 percent), 2,990 trucks and vans (3.2 percent), 2,760 in plant personnel carriers (3 percent), 2,410 passenger cars (2.6 percent) and 145 buses (0.2 percent). Thus excluding bicycles, the 'off-road' vehicles (numbering 83,360) accounted for about 94 percent of the total EVs produced in 1977).

TABLE : 3.1 PRODUCTION OF ELECTRIC VEHICLES

(Number)

| S. No. | Vehicle | FRANCE 1975 | FRANCE 1976 | FRANCE 1977 | GERMANY 1975 | GERMANY 1976 | GERMANY 1977 | ITALY 1975 | ITALY 1976 | ITALY 1977 | UNITED KINGDOM 1975 | UNITED KINGDOM 1976 | UNITED KINGDOM 1977 | JAPAN 1975 | JAPAN 1976 | JAPAN 1977 | USA 1975 | USA 1976 | USA 1977 | TOTAL 1975 | TOTAL 1976 | TOTAL 1977 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. | 17. | 18. | 19. | 20. | 21. | 22. | 23. |
| I. | 'OFF-ROAD' USE | | | | | | | | | | | | | | | | | | | | | |
| 1. | Forklift Trucks | | 200 | | | | 6000 | | 2500 | 1800 | 12360 | 10200 | 10200 | 1420 | 6200 | 9500 | 25000 | 23500 | 21200 | 38780 | 42600 | 48700 |
| 2. | Golf Cars | 100 | | | | | 200 | | | 100 | 150 | 50 | | 800 | 300 | 400 | 38000 | 29000 | 22000 | 39050 | 29350 | 22700 |
| 3. | Load Carriers (In Plant) | | 50 | 300 | - | 120 | 100 | - | 600 | 400 | 1100 | 800 | 1800 | - | 450 | 1800 | 6200 | 5600 | 4800 | 7300 | 7620 | 9200 |
| 4. | Personnel Carriers (In Plant) | 200 | 100 | 100 | | 160 | 120 | | 80 | 100 | 280 | 300 | 180 | 150 | 150 | 60 | 3700 | 1800 | 2200 | 4300 | 2590 | 2760 |
| | Sub-Total (I) | 300 | 350 | 400 | - | 280 | 6420 | - | 3180 | 2400 | 13890 | 11350 | 12180 | 2370 | 7100 | 11760 | 72900 | 59900 | 50200 | 89430 | 82160 | 83360 |
| II. | 'ON ROAD' USE | | | | | | | | | | | | | | | | | | | | | |
| 1. | Bikes | 200 | 250 | 500 | 4500 | 4200 | 2400 | 100 | 350 | 120 | | | 110 | 500 | 600 | 140 | 6400 | 4000 | 600 | 11700 | 9400 | 3870 |
| 2. | Passenger Cars | 150 | 110 | 180 | 60 | 100 | | 1820 | 1380 | 370 | 180 | 500 | 300 | 380 | 660 | 60 | 2570 | 2580 | 1500 | 5160 | 5330 | 2410 |
| 3. | Buses | | 30 | 40 | 16 | 26 | 20 | | | | 9 | 10 | 20 | 10 | 10 | 25 | 25 | 10 | 40 | 60 | 86 | 145 |
| 4. | Trucks and Vans | | | | | | | | | | | | | | | | | | | | | |
| | < 1000 lb payload | | 50 | 240 | 20 | | 50 | 20 | 30 | 30 | 400 | 300 | 260 | 240 | 60 | 50 | 120 | 450 | 600 | 800 | 890 | 1230 |
| | > 1000 lb payload | 25 | 40 | 80 | 60 | 30 | 20 | | | | 2100 | 1700 | 1600 | | 30 | 20 | 150 | 40 | 40 | 2335 | 1840 | 1760 |
| | Sub-Total (II) | 375 | 480 | 1040 | 4656 | 4356 | 2490 | 1940 | 1760 | 520 | 2689 | 2510 | 2290 | 1130 | 1360 | 295 | 9265 | 7080 | 2780 | 2055 | 17546 | 9415 |
| | Grand Total (I&II) | 675 | 830 | 1440 | 4656 | 4636 | 8910 | 1940 | 4940 | 2920 | 16579 | 13860 | 14470 | 3500 | 8460 | 12055 | 82165 | 66980 | 52980 | 109485 | 99706 | 92775 |

(2) Compared to 1975, the number of both 'off-road' and 'on-road' vehicles (including bikes) has gone down from 89,430 to 83,360 and from 20,055 to 9,415 respectively. Thus while the decrease in the number of 'off-road' vehicles has only been of the order of about 7 percent, this decrease was more than 53 percent for 'on-road' type of vehicles.

Characteristics of a few selected current electric vehicles are given in Table 3.2[4]. All except the Fiat City Car are powered by mass-produced or modified lead-acid batteriies. Battery weight is typically between 26 to 32% of the gross vehicle weight and almost 100% or even more as regards the payload. It may be of interest to note that the electric vehicles have cabin heaters fuelled by either paraffin or propane. Had a battery been used for heating it would have represented a significant drain on battery stored energy as for example in the Lucas Midi Bus two heaters are rated at a total of 8 KW and constitute ten percent of the total battery capacity of around 80 KW. The vehicle range in Kms varies from 40 to 100 for Cars, 40 to 80 Km for bus (normally) and 40 to 100 Km for trucks. Some of these vehicles are purpose designed electric vehicles like the Lucas Electric (UK), Electra Van (USA) and the Copper Electric Town Car (USA). However, the characteristic figures do not bring out any significant improvement as compared to other vehicles which are mostly conversions of ICE vehicles, although in purpose built vehicles a greater attention has been paid to such factors as light weight construction, use of low-loss bearings, improved aerodynamic shape, transmission efficiency improvements and use of low-loss tyres, etc.

TABLE : 3.2 CHARACTERISTICS OF CURRENT ELECTRIC VEHICLES

| S. NO. | Vehicle | Country | Make | Range (Kms.) | Max. Speed (Kms./Hour) | Total Weight (Kgs) | Pay Load | | | Battery | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Kgs | No. of Passengers | Total | Weight (Kgs.) | Type | |
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. |
| 1. | CAR | Italy | Fiat | 50 | 75 | 820 | 20 | 2 | 180 | 166 | Ni - Zn | |
| | | U.K. | Enfield | 40 | 64 | 1,120 | 20 | 2 | 180 | 310 | Pb - Acid | |
| | | U.S.A. | CETC | 100 | 90 | 1,500 | | 2 | 160 | 450 | -do- | |
| | | Japan | Toyota | 65 | 70 | 1,250 | | 5 | 400 | | -do- | |
| | | | Laurel | 55 | 85 | 1,920 | | 5 | 400 | | -do- | |
| Range | | | | 40-100 | 64-90 | 820-1920 | 20 | 2-5 | 160-400 | 166-450 | | |
| 2. | BUS | U.K. | Midi | 80 | 80 | 9,870 | | 34 | 2,720 | 2,200 | Pb - Acid | |
| | | | Chloride | 64 | 64 | 16,000 | | 50 | 4,000 | 4,400 | -do- | |
| | | Germany | MAN | 40 | 70 | 16,000 | | 99 | 7,920 | 4,050 | -do- | |
| | | France | Govel | 50 | 45 | 9,000 | | 21 | 1,680 | 2,200 - 2,736 | -do- | |
| | | | Govel | 80 | 60 | 13,450 | | 50 | 4,000 | 4,080 | | |
| | | Japan | Mitsubishi | 170 | 60 | 14,200 | | 70 | 5,600 | | -do- | |
| Range | | | | 40-170 | 45-80 | 9,000-16,000 | | 21-99 | 1,680-7,920 | 2,200 - 4,400 | | |

(Contd)

TABLE : 3.2 CHARACTERISTICS OF CURRENT ELECTRIC VEHICLES

| S. NO. | Vehicle | Country | Make | Range (Kms.) | Max. Speed (Kms./Hour) | Total Weight (Kgs) | Pay Load | | | Battery | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Kgs | No. of Passengers | Total | Weight (Kgs.) | Type | |
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. |
| 3. | VAN/TRUCK | Italy | Fiat | 55 | 60 | 1,857 | 370 | – | 370 | 460 | Pb-Acid | |
| | | | Fiat | 85 | 60 | 3,500 | 1,000 | – | 1,000 | 920 | -do- | |
| | | | Vespa | 50 | 45 | 1,268 | 380 | 1 | 460 | 360 | -do- | |
| | | U.K. | Harbilt | 80 | 53 | 1,640 | 340 | – | 400 | 1,000 | -do- | |
| | | | Lucas | 160 + | 96 + | 2,200 | 400 | – | 400 | 1,000 | -do- | |
| | | | Lucas | 80 + | 80 + | 3,500 | 600-700 | – | 600-700 | 1,000 | -do- | |
| | | | Chloride | 64 | 64 | 7,500 | 1,780 | – | 1,780 | 1,672 | -do- | |
| | | Germany | VW | 70 | 70 | 2,670 | 800 | – | 800 | 860 | -do- | |
| | | | Daimler | 60 | 75 | 4,400 | 1,450 | – | 1,450 | 1,060 | -do- | |
| | | France | Cob | 40 | 47 | 760 | 167 | 1 | 250 | 224 | -do- | |
| | | USA | GE | 48 | 48 | 1,500 | | | | 391 | -do- | |
| | | | Electra | 100 | 88 | 1,480 | 400 | 2 | 560 | 440 | -do- | |
| | | Japan | Daihatson | 60 | 75 | 1,200 | 200 | 2 | 360 | | -do- | |

TABLE : 3.2 CHARACTERISTICS OF CURRENT ELECTRIC VEHICLES (contd)

| S. NO. | Vehicle | Country | Make | Range (Kms.) | Max. Speed (Kms./Hour) | Total Weight (Kgs) | Pay Load | | | Battery | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Kgs | No. of Passengers | Total | Weight (Kgs.) | Type | |
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. |
| | | | Toyo | 50 | 65 | 1,570 | 250 | 2 | 430 | | Pb-Acid | |
| | | | Mitsubishi | 75 | 80 | 915 | | 2 | 160 | | -do- | |
| | | | Toyota | 80 | 60 | 1,515 | 350 | 2 | 510 | | -do- | |
| | | | Nissan | 70 | 50 | 1,425 | 400 | 2 | 560 | | -do- | |
| | Range | | | 40-100 | 47-96 | 915-7,500 | 200-1,780 | | 250-1,780 | 224-1,672 | | |

The Japanese vehicles in Table 3.2 have almost similar performance to other European and American vehicles. However, there have been attempts in Japan to design advanced electric vehicles incorporating the current state of the art with serious consideration to the development of an advanced battery. As a result, radical improvements to the lead-acid battery(with increase in battery performance around twice that of generally used batteries) have been achieved. Besides some hybrid vehicles with two batteries, one supplying energy (for range) and the other power (for acceleration) were also developed. The main characteristics of such advanced battery powered vehicles may be seen in Table 3.3[4].

Although the performance of these vehicles is outstanding specially in terms of range ( 70 to 330 Kms),the battery weight constitutes about 30 to 34 percent of the gross vehicle load and 112 to 142 percent of the pay load. None of these vehicles have so far proved to be cost effective.

TABLE : 3.3 ADVANCED BATTERY POWERED JAPANESE VEHICLES

| S. No. | Vehicle | Make | Range Km | Max.Speed Km/hr | Total Weight (Kgms) | Pay Load | | | BATTERY | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Kgs | No. of Passenger | Total Kgs | Weight (kg.) | Type |
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. |
| Single Battery Pack | | | | | | | | | | |
| 1. | Car | EV1 LIGHTWEIGHT | 175 | 89 | 1,128 | – | 4 | 320 | – | Pb-Acid |
| 2. | Car | EV1N LIGHT WEIGHT | 200 | 101 | 1,427 | – | 4 | 320 | 510 | Ni-Fe |
| 3. | Car | EV2 COMPACT | 180 | 94 | 1,650 | – | 5 | 400 | – | Pb-Acid |
| 4. | Car | EV2P COMPACT | 170 | 85 | 1,480 | – | 4 | 320 | 540 | Pb-Acid |
| 5. | Truck | EV3 LIGHTWEIGHT | 150 | 73 | 1,107 | 200 | 2 | 320 | – | Pb-Acid |
| 6. | Truck | EV3 P LIGHTWIEGHT | 100 | 78 | 1,538 | 300 | 2 | 460 | 445 | Pb-Acid |
| 7. | Truck | EV4 COMPACT | 220 | 85 | 3,347 | 1,000 | 2 | 1,160 | – | Pb-Acid |
| 8. | Truck | EV4 P COMPACT | 110 | 87 | 3,620 | 1,000 | 2 | 1,160 | 960 | Pb-Acid |
| 9. | Bus | EV5 (i) | 330 | 68 | 13,641 | – | 70 | 5,600 | – | Pb-Acid |
| 10. | Bus | EV5 (ii) | 71 | 61.2 | 14,045 | – | 70 | 5,600 | 2,950 | Pb-Acid |
| | Range :- | | 71-330 | 61.2-101 | 1,128-14,041 | | | 320-5600 | 510-2,950 | |
| Battery - Battery Hybrids | | | | | | | | | | |
| 11. | Car | EV1H LIGHTWEIGHT | 140 | 96 | 1,467 | | 4 | 320 | 540 | Iron-air |
| 12. | Car | EV2H COMPACT | 250 | 83 | 1,467 | – | 4 | 320 | 530 | Pb-Acid |
| 13. | Truck | EV4H COMPACT | 250 | 90 | 3,595 | 1,000 | 2 | 1,160 | 1,050 | Zinc-air Pb-Acid |
| | Range | | 140-250 | 83-96 | 1,467-3,595 | | | 320-1,160 | 540-1,050 | |

Effect of Gradients : Battery powered Electric Vehicles are known to perform very poorly on gradients. Even in a purpose designed battery operated vehicle, it is difficult and sometimes not possible to climb 12% gradient under loaded conditions.[5]

Operation Time/Availability : Due to limited range the operation time is very restricted. As may be readily seen from Tables 3.2. to 3.3 that with a range of upto about 80 Kms and speeds of 60 Kms/hour the operation time during one charge is only of about 80 minutes before the batteries have to be recharged.

The Demonstration Project with 5 Fiat E/E2 Electric Vehicles (battery powered) in Denmark confirmed that the overall average operation time per vehicle was 68 minutes per day and most vehicles were used for missions shorter than 30 kilometers per day.[6] The battery charging time was recorded to be 8 hours.

Maintenance : In the Demonstration Project referred to above the total number of days on which the electric vehicles were out of operation because of maintenance and service was 368 days out of a total of 1800 days for 5 vehicles which gave the idleness frequency of 20% compared to the idleness frequency of 3% with other types of vehicles.

## The Claimed Economics

It was mentioned earlier that most of the current literature/work on EVs is biased in favour of the Electric vehicles and in a number of cases does not take into account all the factors specially the infrastructural requirements or are based on assumed/desired performance characteristics of the battery system, life time, etc. which preclude chances of any realistic assessment of the actually available potential. In order to elucidate the point the following comparative Table of various costs given for a 3.7 tonner (GVW) urban delivery vehicle and a diesel vehicle counter part has been given from a leading journal and are typical of such calculations in most of the other Studies. The capital cost of the Electric vehicle has been taken as 10,000 and all other costs have been worked with respect to it. Other assumptions made in these calculations are as follows :-

Life

| | | |
|---|---|---|
| Electric Vehicle | - | 15 Years |
| Diesel Vehicle | - | 07 " |
| Battery | - | 05 " |
| Charger | - | 15 " |

Operation (miles)

| | | |
|---|---|---|
| Annual | - | 14,700 Kms |
| Daily | - | 40 Kms |
| Speed | - | 24 Kms/hour |

| | Urban Delivery Vehicle | |
|---|---|---|
| | Electric | Diesel |
| **Capital Costs** | | |
| Vehicle | 5,630 | 9,020 |
| Battery | 3,610 | - |
| Charger | 760 | - |
| Total Capital Costs : | 10,000 | 9,020 |
| **Standing Charges/year** | | |
| Vehicle depreciation(Years) | 380 | 1,290 |
| Battery depreciation(Years) | 720 | - |
| Charger depreciation(Years) | 50 | - |
| Interest on Capital | 750 | 670 |
| Licence | - | 120 |
| Insurance | 130 | 180 |
| Total Standing Charges/year | 2,030 | 2,260 |
| **Running Costs/Km.** | | |
| Electricity 0.93 KWH/ Km | 0.025 | |
| Diesel 4.3 Kms/Litre | | 0.07 |
| Maintenance materials,labour and overheads incl, tyres and lubricants | 0.37 | 0.07 |
| Total Running Costs/ Km | 0.62 | 0.14 |
| Add standing charge reduced to cost/Km (14,700 Kms/Year) | 0.14 | 0.16 |
| Total Cost/Kms | 0.202 | 0.30 |

It may be seen from the Table that although the infrastructural costs (specially for charging) have not been taken into account in the case of an EV, the battery life of

1800 cycles implicit in the above calculations is indeed very optimistic. Infact the 'desired minimum cycle life' (target) has been mentioned as 1,000 cycles for a battery for Urban delivery van in a much more recent work.[9] Also the life of a diesel vehicle is more than 7 years with 10 years being more realistic. Such comparisons therefore do not give realistic assessment. Also maintenance costs of a battery system are usually grossly under-estimated. It has, therefore, been very rightly mentioned that:-

> "It would take the judicial flair of Solomon to arrive at a set of operating costs for electric versus petrol or diesel vehicles, which would be universally accepted as fair and accurate. Surprisingly, there is little information available from impeccably impartial sources on the subject of comparative running costs".[7]

# C H A P T E R - 4

## THE BATTERY SYSTEM

The most critical component in a Battery Powered Electric Vehicle (EV), is the storage battery itself. Chapter-4 is therefore devoted to a detailed description of the various types of batteries with emphasis on the commercially available batteries most commonly used in EVs, the essential pre-cautions for the safe and efficient use of batteries and the serious bottlenecks associated with their use specially in the context of EVs. The last section briefly reviews the battery industry in Pakistan.

### STORAGE BATTERY

In a storage battery the electrochemical action of the cells in reversible; i.e.. on discharge, they can be recharged to their original state by passing current through them in the opposite direction.

The basic unit of any battery is the cell, consisting essentially of positive plates, negative plates, and an electrolyte. One or more cells connected together for a given purpose constitute a battery. The cells are usually connected in series, but parallel or series-parallel connections may also be used.

The capacity, usually expressed as ampere-hours, is basically dependent on the size (volume and surface area) of the plates. At any particular time, however, it may vary with such circumstances as temperature and discharge rate, etc. The ampere-hour capacity is the additive of all cells connected in parallel.

A storage battery is used in Automobiles, Air-crafts, Electric power and sub-stations, Telephone Exchange, Railway diesel engines, Railway-Car lighting and airconditioning, Emergency lights and power, various portable uses, Marine applications, Submarines and in Electric Vehicles.

Among the commercially available storage batteries, the lead-acid battery dominates the world-wide market. Since a lead-acid battery is the mostly commonly used battery in an EV followed to some extent by a Nickel-Iron battery these type of batteries have been discussed in detail in the following paragraphs.

LEAD-ACID BATTERY

The essential constitutents of a lead-acid cell are lead, lead oxide plates with dilute sulphuric acid ($H_2 SO_4$) as the electrolyte. When the battery is fully charged, the active material of the positive plate is lead dixoide ($PbO_2$); the negative plate is sponge lead (Pb). As the cell is discharged, the electrolyte ($H_2SO_4$) divides into $H_2$ and $SO_4$. The $H_2$ combines with some of the oxygen formed at the positive plate to produce water ($H_2O$). The $SO_4$ combines with the lead (Pb) of both plates, forming lead sulfate ($PbSO_4$).

When the cell is charged, this action is reversed and the lead sulfate ($PbSO_4$) on the positive and negative plates is reconverted to lead dioxide ($PbO_2$) and sponge lead (Pb), respectively. The strength of the electolyte increases as the $SO_4$ from the plates combines with hydrogen from the water to form $H_2SO_4$. The charge and discharge operation can be expressed by the well known 'double sulphate theory' as follows[10] :-

$$PbO_2 + Pb + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2\,Pb\,SO_4 + 2H_2O$$

In a fully charged battery all the acid is in the electrolyte and the specific gravity is at maximum. As the battery discharges, the specific gravity of the electrolyte gradually decreases because the proportion of acid is decreasing and the water is increasing.

Physical Construction

The active materials alone have no rigid mecahnical form or strength and, particularly the positive are poor conductors of electricity. It is, therefore, necessary to mount them in some sort of frame, or 'grid,' to maintain physical shape and to conduct the current to all parts of the material. The three types of lead acid battery manufactured are called 'Flat-Plate', 'Tubular Plate' and 'Plante Plate'. They all have pasted negative plates, but the positive plates from which they derive their names differ considerably.

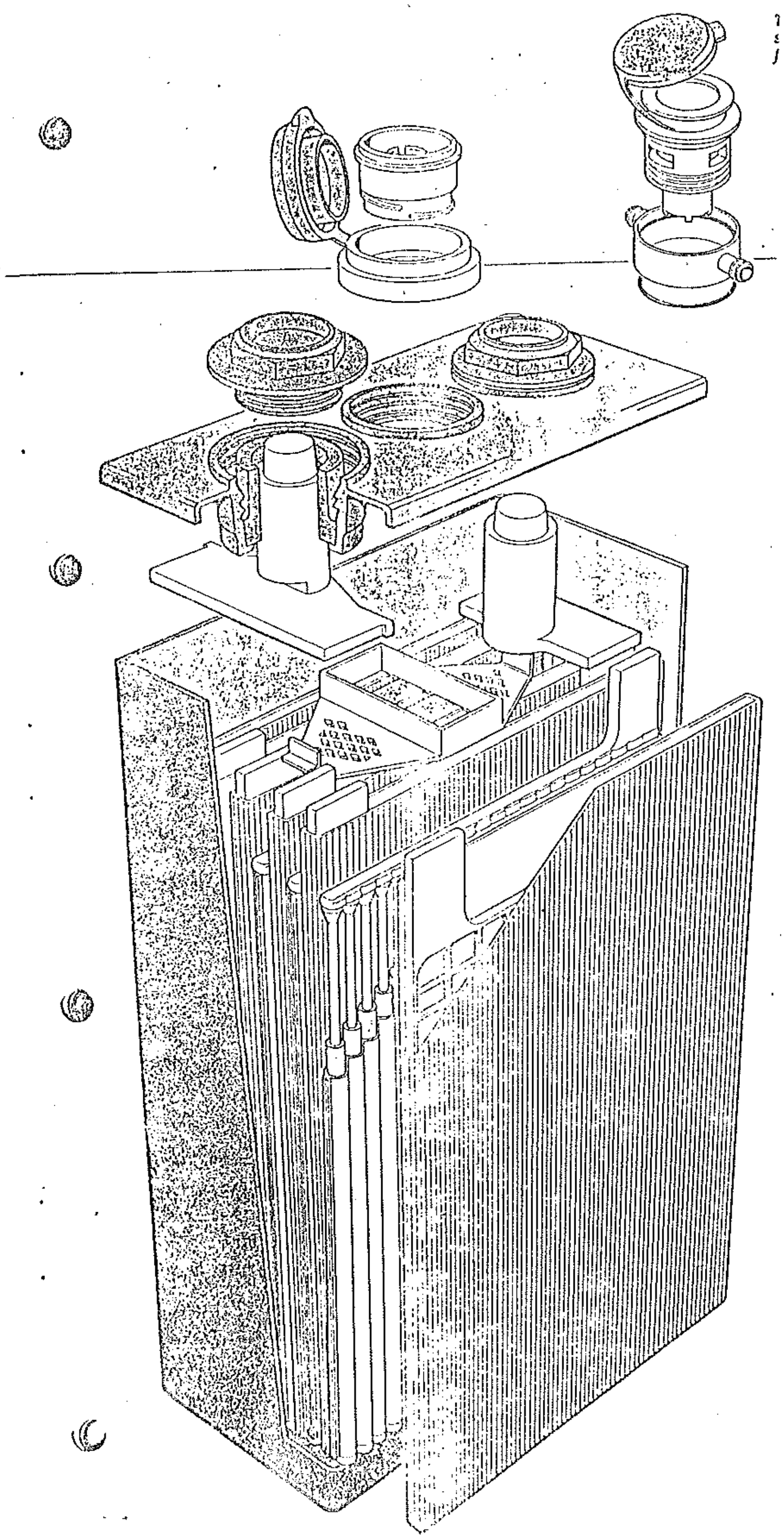
(a) Flat Plate : In a 'Flat plate' or 'Pasted Plate' type, there is a flat lead-antimony latticework into which is pasted finely powdered lead oxides which are later electrochemically 'formed' into the desired active material. This is the most common plate construction and is adaptable to both positive and negative plates. The major production of a lead acid battery is directed towards flat plate type mostly used in automotive application as an SLI (Starter, lighting and Ignition) battery. For deep cycle operation, as in an Electric Vehicle, they have a very short life (50-100 cycles).[10] However these batteries given the best energy density.

(b) Tublar Plate : There are a series of vertical antimonial lead rods which are surrounded by sleeves of an inert porous material such as terylene. The annular spaces in the tubes of the sleeves and around the rods are filled with the active material lead dioxide. The bottoms of the tubes are sealed and joined together to form a semirigid plate. The tubular construction is used only in positive plates.

The negative plate of the tubular cell, which must match the electrical capacity of the positive plate to enable efficient chemical reaction to take place, is of a similar design to the Flat Plat positive, but the lattices in this case, are filled with a sponge of pure lead (Fig.4.1)

The Tubular Plate batteries exhibit much higher cycle life than the Flat Plate design and hence this battery is the preferred type for motive power in EVs. Commercially available batteries have energy densities ranging from 25 to 30 Wh/Kg and a claimed life of 1200-1500 cycles. The two main draw backs have been high manufacturing costs and low power density. The maximum power density, which contrary to the energy density is not related to any particular rate of discharge has been improved by reduction of resistances through out the current path within the cell. In particular the distance between positive and negative plates is reduced by the utilization of tubes with smaller diameters (or flat tubes). This has improved power density and in Europe almost all EVs are equipped with Tubular Plate lead-acid batteries, the main reason being that Flat Plate batteries have an unacceptably low cycle life. High energy density can only be obtained at the expense of a high maximum power density, and it is impossible to have both simultaneously without a serious reduction of cycle life.[9]

Fig. 4.1 Tubular Plate Battery (Chloride Motive Power Cell)7



(c) Plante Plate : In this type, a pure lead plate is cast with complex ridges or grooves, or mechanically furrowed (Tudor type), or a lead-antimony grid into which corrugated lead ribbon is rolled into spiral 'buttons' and the active material is formed electro-chemically from the lead of the plate itself. They are used only as positive plates and have long life in standby service.

The length, width, thickness, and number of plates in a cell are determined by the capacity required for the desired application. It is common practice to have a negative plate at each end of the element, thus making one more negative than positive plate in the cell. Thus a 15-plate cell has 7 positive and 8 negative plates. The 2 outside negative plates are frequently thinner, as the outer surface gets little use.

The positive and negative plates must not come in contact with each other and are prevented from doing so by a separator. Separtors are usually in sheet form and are commonly made of wood, rubber, glass, or plastic. They must be microporous in structure to permit the electrolyte to permeate them.

The element, consisting of the positive and negative groups and separators, is placed in a jar or multicell container which holds the dilute sulfuric acid electrolyte. A cover is placed over the element and sealed to the top of the jar to exclude dirt or foreign material and reduce the evaporation of water from the electrolyte.The cover has a vent plug, which has small holes for the escape of gas and which can be removed for adding water and taking hydrometer readings. The materials used for the jar or container and cover vary considerably with the economics involved and the the type of application. For example, any 'portable' service would require sturdy materials not easily broken, whereas this may not be so critical for a stationary battery installation.

VOLTAGE

The lead-acid cell has the highest voltage (per cell) of any commercial type. It is generally referred to as having a nominal voltage of 2 V, although this varies with the specific gravity and whether or not it may be discharging or on charge at the time. Thus a 3-cell battery is usually referred to as a 6-V battery, a 60-cell battery as a 120-V battery, etc.

ELECTROLYTE

The electrolyte is a dilute solution of sulphuric acid and water, being known by the trade as "battery grade". The specific-gravity value is its relation in weight to an equal volume of water. Specific gravity is measured by a hydrometer, which floats in the solution at a depth varying with the gravity. A calibrated scale on the hydrometer stem indicates the gravity value at the point where it emerges from the solution. It is never necessary to add electrolyte to a battery except to replace loss due to spillage or leakage in some form.

The full-charge gravities most commonly used, usually expressed as a range of ± 10 points (1 "point" equals 0.001), and certain representative applications are :-

1.275. Heavily worked, or 'cycled', batteries such as electric industrial trucks.

1.260. Automotive and aircraft service.

1.245. Partly cycled batteries such as railway-car lighting and large engine-starting batteries, etc.

1.210. Batteries in stationary standby or emergency service.

In tropical climates or where the temperature averages 90°F or higher, it is customary to reduce these values by 30 or 40 points.

Specific Gravity of the Electrolyte during Charge/Discharge :

The decrease in specific gravity on discharge is proportional to the amount in amper-hours discharged. Thus at any time the gravity is an approximate indication of the state of charge of the battery. This is determined by comparing the gravity as read with the full-charge value and the published "specific-gravity drop", which is the decrease from full charge to nominal discharge.

During the early part of the charge there is nothing to mix or stir the electrolyte, and some of the heavier acid coming from the plates does not rise to the top of the cell and cannot be read by the hydrometer. During this part of the charge, therefore, the hydrometer reading does not represent the true state of charge of the battery. Later in the charge, when gassing begins, all the electrolyte becomes more completely mixed and the gravity, as read at the top of the cell, rises rapidly to its full-charge value.

Battery Capacity: The capacity of a storage battery is its ability to deliver energy. It is usually expressed in ampere-hours which is simply the product of the discharge in amperes over a number of hours. However, a capacity of say 200 AH has to be qualified by the many factors which influence a battery's capacity, the principal ones being discharge rate, temperature, specific gravity and final voltage.

(a) Discharge Rate: The higher the discharge rate in amperes, the fewer total ampare-hours a battery will deliver under otherwise similar conditions. This relationship varies somewhat with different types of plate and cell construction.

(b) Temperature: Many chemical reactions are accelerated at higher temperatures, and this is true of those in a storage battery. Also, the resistance and viscosity of the electrolyte are reduced at higher temperatures, thus reducing the voltage drop and energy loss within the cell. These combine to increase the battery's capacity at higher temperatures and reduce it at lower temperatures.

(c) Specific Gravity: This affects cell capacity as electrolytes of higher gravity have more acid in contact with the active material and available for the chemical reactions than do electrolytes of lower gravity. Also, the higher-gravity electrolyte has a lower electrical resistance, which letter maintains the terminal voltage of the cell.

The choice of full-charge gravity is a compromise of many factors. Some effects of difference in gravity (in varying degree), other features being the same, are:

| Higher Gravity | Lower Gravity |
| --- | --- |
| More capacity | Less capacity |
| Shorter life | Longer life |
| Less space required | More space required |
| Higher momentary discharge rates | Lower momentary discharge rates |
| Less adaptable to "floating" operation | More adaptable to "floating" operation |
| More standing loss | Less standing loss |

(d) Final Voltage

In general, a battery may be discharged without harm at any rate of current it will deliver, but the discharge should not be continued beyond the point where the cells approach exhaustion or where the voltage falls below a useful value.

Discharging at a constant current value, the initial voltage depends on the rate of discharge and the normal characteristics of the cell. As the discharge continues, the cell voltage will slowly decrease during perhaps the first 70 to 80% of the total time period. It will then fall more rapidly, passing over the "knee" of the curve to the "final" voltage as full time and capacity are reached.

The total ampere-hours available varies with the rate of discharge, being lower at higher rates. This lower ampere-hour capacity does not, however, represent any specific loss of energy — it simply means that the cell voltage falls to its minimum useful value in a shorter period of time at that rate.

During discharge there is a small rise in battery temperature, perhaps 5 to 10°F, depending on the type of battery assembly from the standpoint of heat dissipation. The actual chemical reactions on discharge absorb a small amount of heat, which would tend to cool the battery slightly, but the heat due to the internal resistance ($I^2R$) of the cell is greater so that the net result is an increase in temperature.

A battery should not be discharged beyond the point where the cells approach exhaustion. This is referred to as "overdischarging" and can have harmful results, particularly if the battery is not promptly recharged.

Charging Characteristics

In general, a battery may be charged at any rate in amperes that will not produce excessive gassing or temperatures above 110°F (125°F for short periods). Another index is that any rate is safe which does not result in a cell voltage of more than 2.4 V while the current is above the "normal" or "finish rate" of charge. The manufacturer usually determines and publishes such a "normal" or "finish rate" in amperes for each type and size of cell made. This rate is the current value which can safely be used at any time when charging is required and which can be continued to the completion of the charge without causing excessive gassing or high temperature. This finish rate is usually between 4 to 10 A/100 Ah of the battery's capacity (8 h) depending on the type of cell assembly. When a number of high-capacity cells are assembled as a compact mass, the available surface for heat dissipation is much less than for separate individual cells and comparatively lower finish rates must be used to avoid high temperature.

A battery which is partly or completely discharged can safely absorb much higher currents than the finish rate, upto possibly 10 times that value, but as it approaches full charge, the current must be reduced, either gradually or in one or more steps, to the finish rate or less. In practical applications, it is seldom necessary to use currents of more than 4 or 5 times the finish rate to charge in the time available When the charge is complete, it should be stopped or reduced to a low value.

In any type of service, a battery should receive the "correct" amount of charge, sufficient to charge it fully or maintain it in that condition, but no more. Undercharge or overcharge should be avoided to whatever extent is practical under the conditions of use.

An insufficient amount of charge (even to a small degree, if continued) will cause gradual sulfation of the negative plates, with eventual loss of capacity and reduction of battery life.

An excessive amount of charge will tend to "form up" (corrode) the grids of the positive plates into lead dioxide, thus weakening them physically and increasing their electrical resistance. If the overcharging is at comparatively high rates, the gassing will be excessive and this tends to wash the positive active material from the plates. All these results reduce the capacity and shorten the life of the battery.

To determine whether or not the amount of charge is correct, there are simple checks. If the proper amount of charge is being given, the specific gravity will reach its approximate full-charge value at the end of a recharge or remain at that value in floating or similar service. Also, the amount of water required by the cells will be a normal minimum. If the gravity does not reach full-charge value or tends to show a continual decrease, the battery is not getting enough charge and more should be given. On the other hand, if the gravity reaches or remains at full charge and an excessive amount of water is required, the battery is receiving too much charge and the amount should be reduced.

It is difficult to specify the "normal" water requirements, as they vary with batteries of different full-charge gravities and with the types of service from the standpoint of the amount of cycling (charge and discharge) which the battery receives. The manufacturer can usually, however, specify an approximate value which will serve as a guide for a given application.

Charging Methods

(a) Cycle Charging

This referes to the complete recharge of a battery after it has been partly or normally discharged. For this charging, a time of 8 hours is usually required as it cannot be accomplished safely in a much shorter period under practical conditions, although it may, of course, be extended over a longer time if available. A nominal assumption is that about 110% of the ampere-hours discharged must be returned to charge the battery fully. This requires a starting rate of 20 to 25 A/100 Ah of the battery's rated capacity. This current is either "tapered" (reduced gradually) to the finish rate at the end of charge or reduced in one "step: (referred to as "two-rate" charging) when the charge is 80 to 85% complete. When full charge is reached, the charge should be stopped; this is normally done automatically.

(b) "Boost" Charging

"Boost" charging, as applicable to motive power batteries, is additional charging during short periods, to extend the battery's capacity to complete the day's work. The current (in amperes) used should not exceed the value of the ampere-hours still remaining "out" of the battery at the end of the charging period. In practice with modern charging equipment, the battery may simply be placed on charge in the usual way. However effects of Boost Charging an Cycle Life need to be fully assessed.

(c) "Quick" Charging

As applied to automobile batteries should preferably be continued only long enough to make the battery serviceable, the completion of the charge being accomplished by the car generator in the usual way. To avoid prolonged charging at the high current rates commonly used, most of these charges have an automatic cutoff which stops the charge when the battery reaches a predetermined temperature.

(d) <u>Floating Charge</u>

This type of charging is one where the battery is continuously connected to an electrical system, including a charger and load. The charger is designed to maintain a constant voltage throughout its load range. The value of this voltage is such that it supplies to the battery sufficient current to overcome its internal losses and keep it fully charged, but without appreciable overcharge. Following any discharge, the battery will automatically draw a higher current which will decrease, as full charge approaches, until it is again reduced to the low maintenance value. It is merely necessary to keep the voltage of the charger at the correct value to operate the battery properly under all normal conditions of system load and temperature.

Where its use is practical, this type of operation is considered ideal, as it requires the least maintenance and results in the longest battery life.

(e) <u>Partial Float</u>

This is similar to "full float" but applies where the charging current is available only a portion of the time.

(f) Two-rate Charging

This has been used considerably in the stationary-battery field. It is usually a second choice after floating operation, as the equipment is less expensive. While less desirable than floating, it frequently is satisfactory. Its normal application is on systems where there are a small continuous load and heavier short-time or momentary loads.

(g) Trickle Charge

This is a continuous constant-current charge given to a battery to maintain it in a fully charged condition, with no external load connected to it. This may be used for batteries in storage or in standby service, where their only use is in an emergency such as failure of the normal power supply. In setting up such a trickle charge, a current value of 50 to 100 mA/100 Ah of battery capacity is a good trial value. However, the voltage should be checked and the current readjusted until an average voltage of 2.15 to 2.17 V/cell is maintained.

Only comparatively low-gravity batteries are suitable for "floating" or the various other methods of continuous charging. High-gravity batteries in standby service or storage should be kept charged by periodic recharges.

Current Requirements

The current drawn by batteries which are floated from a constant-voltage source varies with:

(1) The voltage of the charging source : The current will approximately double for each increase of 0.05 V/cell (2.15 to 2.20, etc.) and, of course, will be reduced to one-half for a similar decrease.

(2) Temperature : An increase of 15°F in temperature will approximately double the current drawn, and a similar decrease will reduce it to one-half.

(3) Battery Age : Owing to the increase of the internal losses in a cell, the current which it requires to maintain full charge also increases. No accurate values can be given, but here also the requirements probably double during the battery's life.

Equalizing Charge

An equalizing charge is necessary because each cell in a battery has its own characteristics and therefore requires a slightly different amount of charge. Such an equalizing charge is provided by a continuous low current used to stabilize the voltage and specific gravity of the cells.

A battery must be brought to state of full charge to avoid excess sulfation; yet appreciable overcharge must also be avoided. To accomplish this, it is common practice to stop daily or other frequent recharges when the battery is nominally but not completely recharged and then give a periodic 'equalizing charge'. Such a charge should be continued until successive readings of gravity and voltage show no increase over a period of several hours. In practice it is usually done by continuing the charge by time clock for a certain period which experience has shown to be adequate. The frequency of these equalizing charges varies with the service application.

Efficiency

The efficiency of a battery is the ratio of its output to its input and can vary widely depending upon use. It is usually expressed as a percentage and can be given in terms of ampere-hours or watt-hours.

(a) Ampere-hour Efficiency : This is the amount of charge which can be taken out of a cell, in relation to the amount which must be put back to restore it to its original condition.

The amphere-hour efficiency of a lead-acid battery is approximately 90%, depending on working conditions. Thus for every 100 Ah fed into the battery, the output is 90 Ah.

(b) Watt-hour Efficiency : The Watt - hour efficiency represents the 'energy' efficiency. Watt-hours are the product of ampere-hour and average voltage. For a given amphere-hour efficiency, the watt-hour efficiency can be obtained by multiplying the ratio of 'average volts on discharge' to 'average volts on charge'. With an ampere hour efficiency of 90%, an average discharge voltage of 1.9 and an average charge voltage of 2.4, the watt-hour efficiency would be : $\frac{90 \times 1.9}{2.4} \times \frac{100}{} = 71.3$ percent which is a fairly representative figure of the watt - hour efficiency. It is thus obvious that anything which reduces the discharge voltage or increases the charge voltage will reduce the watt - hour efficiency. Thus the best watt - hour efficiency can be obtained at low current rates, but for practical purposes, the charge currents should always be within the limits recommended by the battery maker.

Local Action : This refers to the internal losses of a battery standing on open circuit or when on float charge, and without considering any losses incidental to any discharge. It is due to the local chemical action between component parts of the plates and is almost entirely in the negative plates. For example, the negative active material - pure lead - and the antimony of the grid and any other constituents of the alloy react with the electrolyte as a 'cell'. If it were practical to use a pure lead grid and eliminate every trace of impurity in the cell, there would be virtually no local action.

The degree of local action may be expressed either as the percentage loss in capacity per month on open circuit or by the amount of current required on float or trickle charge to overcome it and keep the battery fully charged. This varies with temperature, being greater at high temperatures.

Gassing : A battery cell cannot absorb all the energy from the charging current toward the end of charge, and the excess energy dissociates water by electrolysis into its component gases hydrogen and oxygen. The oxygen is liberated at the positive plates and the hydrogen at the negative. When a battery is completely charged, all the energy, except the small resistance loss, is consumed in this electrolysis.

During a recharge, gassing is first noticed when the cell voltage reaches 2.30 to 2.35 V/cell and increases as the charge progresses. At full charge, when most of the energy goes into gas, the amount of hydrogen liberated is about 1 $ft^3$/cell for each 63 Ah input. In as much as a 4% content of hydrogen in the air may be hazardous, the above value may be used to relate the maximum amount from a given battery to the size of the room in which it is located.

Mossing : This describes the possible deposition of a spongelike layer of lead on the negative plates or strap. This material was originally shed from the plates (mostly the positives) in fine particles and circulated throughout the cell by gassing, falling on both the positive and the negative plates. When in contact with either plate, it is changed to the active material of that plate. However, it is loose and non-cohesive on the positive plate but cohesive and adhesive on the negative plate and builds up on the top edge and possibly along the side edges of the plate. It can accumulate to such an extent that it bridges over or around the separators, touching an adjacent positive plate and causing a partial short circuit.

The accumulation of any appreciable amount of moss is usually an indication of overcharging in ampere-hours or high charging currents in amperes, either of which should be corrected.

Sediment : There is a tendency for some of the active material on the surface of the plates to separate from the main body of material and settle to the bottom of the container. This is counteracted in various ways. The material may contain a 'binding agent', or it may be held in place by the various types of tubular construction or on flat plates by perforated glass, rubber, or plastic sheets or mats known as 're-tainers'.

Despite these means, a small amount of such material may fall from the plates, most of it usually from the positives, and a certain space in the bottom of the container, below the plates, is usually reserved for this 'sediment'.

With proper floating types of operation, this sediment is entirely negligible and after years of operation may amount to hardly more than a layer of dust. In active cycle service, an appreciable quantity may accumulate after years of use, but the size of the sediment space is designed to accommodate all that will fall during the battery's life. Thus it should never be necessary to remove or 'clean' the sediment from a battery.

Certain types of abuse, primarily excessive overcharging or charging at high rates, will accelerate the accumulation of sediment and shorten the useful life of the battery. If the sediment increases to the point where it reaches the bottom of the plates, it will partly short-circuit them and cause failure.

Temperature : The operating temperature of a battery should preferably be in the 'normal' range of 60 to 80°F. Higher temperatures given some additional capacity at the time but will reduce total battery life. High temperature (125°F and higher) can actually damage some of the battery components and cause early failure.

Low temperatures reduce capacity but will prolong battery life under floating operation or in storage.

Internal Resistance : The actual ohmic value of the internal resistance of a cell is low, and no general answer can be given, as it varies with the state of charge, specific gravity, cell size in ampere-hours, temperature, physical construction, and the condition of the cell or the degree to which it is worn out.

Dry Charged Battery : When it is desired to keep or store new batteries for a considerable time before they are required, they are frequently manufactured or prepared in a 'dry-charged' condition. This consists essentially in charging and drying the plates, before assembly, in an atmosphere devoid of air or oxygen. All elements of the assembled cell are completely dry, and the cell is partly or completely sealed to keep out any moisture. Such batteries must be stored in a cool, dry location until ready for use, and under these conditions the plates will retain most of their charge for as long as perhaps 2 years.

Maintenance : The routine maintenance of storage batteries varies widely with the type of battery and its use. A Battery in frequent heavy duty cycle service like in an EV will require regular watering, charging and cleaning, etc.

Proper charging is the most important factor in battery service and life, and the proper method for each application should be carefully followed.

Water should be added at necessary intervals to keep the electrolyte level between its normal upper and lower limits. The plates must not be allowed to become dry. Water must be of 'approved' quality. Batteries must be kept clean and dry to the extent that no corrosion, dust, or moisture offers a conducting path to partly short-circuit the cell or contact 'ground'. Lead acid batteries do not require any routine overhead or solution changes during their entire life except as a result of accidental damage.

## Nickel - Iron Battery

The nickel-iron battery is unique in many respects, both its chemistry and physical properties being different from those of other types. It is often known as an 'alkaline' battery because of the electrolyte used.

In a fully charged cell, the positive active material is nickel oxyhydrate ($N_iOOH$), the negative is metallic iron sponge (Fe), and the electrolyte potassium hydroxide (KOH) and water with the addition of lithium hydroxide. He chemical reactions during discharge produce intermediate transitory compounds, but the end result is a transfer of oxygen from the positive to the negative, leaving the positive as nickel hydroxide, $N_i(OH)_2$, and the negative as iron hydroxide, $Fe(OH)_2$. Neglecting the intermediate reactions, the end result is :

$$2N_iOOH.H_2O + Fe \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2\,Ni\,(OH)_2 + Fe(OH)_2$$

The electrolyte takes no part in the chemical reaction, its composition is unchanged. It does, however, act as a transfer agent by 'accepting' oxygen at the positive during discharge and 'depositing' it at the negative. On charge, conversely, the action is reversed, and the positive and negative materials revert to their original charged state. The active material is finely ground powder and requires a 'container' to give it a physical form and provide a conductor to the external circuit.

The positive material is encased in perforated nickel-plated steel tubes, made by spirally winding a flat strip into tubular form. The ends of these tubes are closed by crimping, and the tubes themselves are reinforced at intervals by annular steel rings. Since the active material is a poor electrical conductor, it is interspersed with alternate layers of metallic nickel flake to increase its conductivity to acceptable levels.

The negative material is encased in flat, perforated nickel-plated steel pockets to accomplish a similar result. No additional conductive material is required.

The 'plate' is formed by grouping the desired number of positive tubes or negative pockets and crimping or welding them together or to a nickel-plated sheet-steel frame.

Voltage : The voltage of nickel-iron cells is usually referred to as being 1.2 V; thus a 10-cell battery is nominally considered a 12-V battery, etc. The actual voltage at any time, however, depends on whether it is on open circuit, on discharge, or on charge and, in the latter cases, on the current rate and the state of charge. The open-circuit voltage varies between 1.25 and 1.35 V, but its relation to the state of charge is not sufficiently definite to be used as an indication of that condition.

On discharge, the voltage will decrease to a value where it is no longer effective for the application to which it is put. This is referred to as the 'final' voltage. It varies with the rate of discharge, being lower at higher rates and vice versa. The most commonly used value is 1.0 V/cell, although either higher or lower ones may be more suitable for particular uses.

Conversely, on charge, the voltage rises and follows a distinct pattern through out the charge, to a maximum value varying with the charging rate. At the rates most commonly used, this maximum voltage is 1.7 to 1.8 V/cell.

Electrolyte : The electrolyte is a solution of potassium hydroxide (KOH) and water, with the addition of lithium hydroxide. While necessary to the chemical reaction, it is not significantly changed by it throughout the normal range of charge and discharge.

The specific gravity of the electrolyte of a new cell is about 1.210 to 1.215 at the normal electrolyte level at 77°F, this one value being used for nearly all types. This gravity slowly decreases over months or years owing to loss from spray during charge and possible spillage. The electrolyte also tends to carbonate because of contact with the air. When the gravity decreases to about 1.160, it definitely affects the capacity and the entire solution requires renewal. This may be necessary several times during the life of the battery.

Capacity : The capacity of the alkaline storage battery is expressed in ampere-hours, the product of the discharge in amperes over a number of hours. However, a figure such as 100 Ah has little significance unless it is qualified by the various factors which influence the capacity. The principal ones which must be considered are :

(1) Discharge Rate, (2) Temperature, and
(3) Final Voltage.

Discharge Rate : The higher the discharge rate in amperes, the fewer total ampere-hours a battery will deliver under otherwise similar conditions. This relationship varies slightly with different cell types.

The primary reason for this is the internal resistance of the cell, which causes a voltage drop or loss within the cell itself. The higher the current being discharged, the greater is this internal voltage drop and, therefore, the less voltage is available for the external load. The discharge rate most commonly used as a standard reference for alkaline batteries has been the 5-h rate, although a 6-h basis is now frequently used. The difference between these two is only a couple of percent. Other hourly ratings can be supplied to cover applications requiring them. All such ratings are equally correct, as long as they are properly specified.

In as much as the electrolyte does not change during normal charge and discharge there is no lack of diffusion to affect the capacity.

Temperature : The reaction of a storage battery are accelerated at higher temperatures, and the resistance and viscosity of the electrolyte are reduced, it having a negative coefficient of resistance. Thus the voltage drop within the cell is less, and the resultant capacity is greater. Conversely, at lower temperatures the capacity is reduced.

Discharge Characteristics : These batteries may be discharged at any rate of current they will deliver, but the discharge should not be continued beyond the point where the cell nears exhaustion. They are well adapted for low or moderate rates of discharge, but not for extremely high rates such as large engine starting.

At any constant rate of discharge, the cell voltage decreases through out the discharge until the appropriate final voltage is reached.

The lower capacity at high rates does not, however, represent a comparable loss of energy; it means that the voltage falls to its final value in a shorter period of time.

The state of charge of an alkaline battery cannot be determined as readily as with other types. The specific gravity does not change appreciably during discharge or recharge, and a gravity reading, therefore, has no significance. The only practical means is to read the voltage of a pilot cell under a momentary high-rate discharge. A device known as a 'test-fork' is available for this purpose and consists of a resistor drawing a high current and a voltmeter to measure the cell voltage at the time. By a chart or table, the voltage reading can be related to the state of discharge of the battery. While not at all a precise means of determining the state of charge, it does meet most practical requirements.

Maintenance : The following precautions are necessary for proper operation and long life.

Proper Charging : This is the most important factor. Every effort should be made to give the correct amount of charge at proper rates and with adequate ventilation.

Water Addition : Approved water must be added at necessary intervals to maintain the electrolyte level between the tops of the plates and its specified height. Do not-overfill, as this may cause overflowing during charge.

Cleaning : The battery must be kept reasonably clean and dry to avoid any paths of electrical 'leakage' between adjoining cells or from cells to conducting trays or boxes. Such leakage will cause electrolytic action, resulting in corrosion of the steel containers.

These batteries should preferably be cleaned with steam or hot water and blown dry with compressed air. They should be raised off the floor when this is done in order that any dirt will be completely flushed away. Always keep filler caps closed during such cleaning.

After cleaning protective coatings should be renewed.

Solution Change : Over long periods of time the specific gravity of the electrolyte will decrease owing to small amounts lost through spray, etc. When the corrected value falls to about 1.160, the entire contents of the cells should be replaced. The 'renewal solution', has a specific gravity of 1.245 at 77°F. Solution renewal is usually necessary only perhaps twice during the battery's life.

Efficiency : The efficiency of a battery varies widely depending on the circumstances of use. In ampere-hours, it is usually considered that the recharge should equal 12% of the the discharge, giving an efficiency of 80%. However, the average voltage on charge is considerably higher than on discharge, in the approximate proportion of 35% giving a voltage efficiency of 75%. Combining these two would result in a watt-hour (total energy) efficiency of about 60% which can be considered as a reperesentative figure for a Nickel-Iron Battery.

## Search for Improved Traction Batteries

The most common battery system commercially available for Motive Power application is the lead-acid battery followed to a lesser extent by the Nickel-iron battery. The lead-acid Battery has given long service in a wide variety of applications but despite all the improvements for Motive Power purposes it suffers the drawback of not producing optimum electrical energy per unit weight or volume. Thus the lead-acid battery is capable of meeting only the needs of a limited semi-flexible daily use in urban environments, e.g. short-trip delivery vans and industrial vehicles. At present electrical vans are capable of speeds of 40 to 80 Kms an hour and have ranges between 50 to 80 kilometeres before battery recharging is needed.

Battery powered electric vehicle is thus unable to offer the same flexibility of use and performance as provided by today's petrol or diesel-fuelled vehicles. The future of the battery powered electric vehicle as a viable transport alternative to the I.C. engine depends upon the development and commercial availability of an economical, high energy and high power-density, long-life, low maintenance battery with minimal recharging time.

Many other battery types potentially offer considerable improvement in energy and power density over the conventional lead-acid system. Some of the important battery systems which have received attention from research bodies[7,9] in a number of countries are briefly described below :-

(1) Lead Acid

Improvements to the lead acid battery are being sought in energy density, service life, rechargeability, maintenance needs, and manufacturing processes and costs.

Present lead-acid batteries produce only about 1/5 of the energy of which they are theoretically capable. Improvements in energy density require a decrease in weight of support materials that do not actively help in energy storage, e.g. grids, intercell connectors, terminals, outer containers etc. Modern trends are meeting the challenge of minimising overall weight and volume by selecting optimum packaging and structural materials. Aluminium, titanium and metal-coated plastics have been tested as lightweight grids and the weight of the battery case has been reduced. Increasing the effective surface area of the plates is also important in increasing efficiency.

(2) Nickel iron

Nickel-iron batteries are good as regards their long cycle life and research in Japan, the U.S.A. and Sweden has produced improved batteries with energy densities about 2 times that of conventional lead-acid systems. Problems include poor power density, low charging efficiency, high self-discharge,high nickel costs and low cell voltage which requires more cells for a given battery voltage.

(3) Nickel-zince

This system consists of nickel oxide positive and zinc negative electrodes in potassium-hydroxide electrolyte. Present batteries have energy densities about 2½ times that of the conventional lead-acid. The major factor restricting the commercialization of nickel-zinc batteries is the rapid loss in capacity as a function of deep charge cycle life. Redeposition of zinc during charging results in growth of dendrites, which penetrate the battery separators and short through to the positive electrodes and also in redistribution of active material which leads to loss in battery capacity.

(4) Iron air

Metal-air systems use oxygen from the air as positive active material and suffer from the problems of limited power, carbonate formation, poor oxygen electrode efficiency and limited cycle life that are common to all batteries and fuel cells using air cathodes in alkaline electrolyte. Much effort has been directed toward the development of a rechargeable, low cost, high rate, oxygen electrode. Such materials must exhibit good resistance to anodic corrosion processes during charging and to mechanical attack caused by the gas generation. Good results have, however, been obtained on layered nickel structures by Swedish and German research groups.

(5) Zinc-Air

This is the zinc equivalent of the iron-air system. The most promising system overcomes problems of zinc shape change and dentritic growth by using a circulating system of zinc powder suspended in the electrolyte. The slurry is pumped through tubular air cells during discharge, and cell life times of up to 600 charge/discharge cycles have been claimed.

(6) Zinc-chlorine

This battery system is a flow type using circulating electrolyte at 50°C from which zinc and chlorine are generated at bipolar graphite electrodes during charging. It is claimed that such a power source will give a small car a 155 mile range. The main problem with zinc-chloride battery is the size and complexity of the plumbing system, which impose serve weight, volume and cost penalties.

(7) Sodium Sulphur

Of all the alternatives to lead-acid, this couple is believed by experts to be the most viable alternative. If sodium and sulphur are allowed to react together energy is evolved. If the sodium and sulphur are separated chemically, but allowed to react electro-chemically, electricity is produced.

Unlike most batteries which have solid electrodes and liquid electrolytes, the sodium sulphur battery has liquid electrodes, which are separated by a solid electrolyte-Balumina, a compound of alumina and soda. It will conduct sodium ions but exhibits a very low electronic conductivity. The cells are hermetically sealed and do not require topping up. The charging efficiency is almost 100% eliminating the need for equalizing charges.

Because sodium and sulphur are cheap and abundant in the earth's crust, the price will be about the same per KWh as the lead-acid battery, initially, but is expected to be lower as production volume increases.

Sodium sulphur will store up to five times the energy of conventional lead-acid batteries per unit weight and up to three times the energy per unit volume. It is maintenance free, and there is no equivalent of gassing.

A probable problem with the sodium sulphur battery is that it must be heated to 300°C as the cell will only operate when the sodium sulphur and sodium sulphide are molten.

Table - 4.1 summarises the likely achievable performance of selected batteries.[10]

TABLE : 4.1 - LIKELY ACHIEVABLE PERFORMANCE OF EXISTING AND UNDER DEVELOPMENT SELECTED BATTERIES[10]

| S. NO. | Description | Lead Acid | Nickel-Iron | Nickel-Zinc | Iron Air | Zinc-Air | Zinc-Chlorine | Sodium Sulfur |
|---|---|---|---|---|---|---|---|---|
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
| 1. | Electrolyte | $H_2SO_4$ | KOH | KOH | KOH | KOH | $Z_nCl_2$ | Beta-$Al_2O_3$ |
| 2. | Voltage (V) - Open Circuit | 2.05 | 1.37 | 1.71 | 1.27 | 1.65 | 2.12 | 2.1-1.8 |
| | - Discharge at 2 hr rate | 1.09 | 1.02 | 1.06 | 0.07 | 1.02 | 1.85 | 1.7-1.4 |
| 3. | Energy efficiency, charge-discharge(%) | 75 | < 60 | 75 | 40 | 55 | 65 | 70-75 |
| 4. | Specific power (W/Kg) - Peak | 120 | 440 | 400 | 60 | 100 | 280 | 240 |
| | - Sustained | 25 | 220 | 200 | 50 | - | - | 120 |
| 5. | Life (to 80% discharge) cycles | 500 | 2000 | 350 | 200 | 100 | 100 | 2000 |
| 6. | Recharge time (hr) | 5-8 | 4-7 | 3-6 | 4-5 | 5-8 | 5 | 7-8 |
| 7. | Operating temperature (°C) | - 20<br>+ 50 | 10<br>50 | - 30<br>+ 40 | 0<br>+ 50 | 0<br>+ 60 | 0 | 300-400 |
| 8. | Cement Status | ←——— Existing | | ——— Under Development ———→ | | | | |

## Battery Industry in Pakistan

### Introduction

The storage battery industry is an important lead based industry which plays a vital role as ancillary for automobile industry in Pakistan. There was no storge battery plant in the country before independence. The pioneer unit of M/S. Brisk Engg. Works, Lahore was set up in late 1947.[11,12] At present there are about 18 units including three integrated units in the country engaged in production of storage batteries for light and heavy vehicles like cars, buses, trucks, tractors, etc. as well as for motorcycles. The first integrated unit namely Exide Batteries, Karachi was established in 1953 and the second namely Atlas Battery Limited Karachi in 1966 with the technical collaboration of J.S. Battery (Japan). The third large integrated unit has recently gone into production (July, 1987) at Hub Chowki Baluchistan with the technical collaboration between M/S Automotive Company Limited with Farukhawa Battery of Japan.[13] Several other units came into existence in the late 1960s but closed down for various reasons. There are now about 18 units in the organized sector with a combined installed capacity of about 500,000 batteries per year.

The local production covers a wide range of lead acid batteries made for motorcycles, cars, buses, trucks, tractors, etc. while also catering to the defence needs of the country. The locally produced batteries are mostly for automotive use and follow the Japanese Specification (JIS) for exclusive use in the Japanese vehicles. Some batteries for stand by application are manufactured locally by Chlordie Pakistan Ltd. However no traction type of batteries specially tubular plate lead acid battery is manufactured locally.

Lead-acid storage batteries have passed through numerous innovations and improvements since its introduction, and some innovations are being adopted by the local industry as well. The traditional hard rubber containers have been replaced by plastic or polypropylene which are lighter, more durable, allow for automatic scaling and offer more room for electrolytes. GP glass pulp separators which have excellent acid resistance and insulation properties are finding increased application in quality storage batteries.

Before the commissioning of the third large integrated plant for automotive batteries, about 75 percent of the total production came from Chloride Pakistan and Atlas Batteries out of which the share of Chloride Pakistan was roughly 60 percent. Presently about 90 percent of the total production of the storage batteries is for light and heavy vehicles and the remaining 10% is for motorcycles. The remaining units are rather small and have mainly confined their operations to assembly. These units partly import their requirements of components and partly procure them from local sources. Bulk of the capacity is for car and heavy vehicle batteries. However, Grand batteries Limited, Lahore is engaged in the manufacture of diesel locomotive batteries of which the sole user is Pakistan Railways.

Production of Storage Batteries and Battery Parts :

Inspite of a large and growing demand of storage batteries, the industry has been unable for many years to operate at full capacity. Production of storage batteries increased from 160,338 in 1979-80 to 230,588 in 1983-84, showing an average increase of 9 percent per annum. However since then it has registered a downfall to the extent of 47 percent in 1986-87 over 1983-84 as may be seen from Table 4.2.

TABLE : 4.2. PRODUCTION OF STORAGE BATTERIES

| Year | Production (Number) | % Increase/ Decrease |
|---|---|---|
| 1979-80 | 160,338 | - |
| 1980-81 | 222,513 | + 39 |
| 1981-82 | 146,316 | - 34 |
| 1982-83 | 224,056 | + 53 |
| 1983-84 | 230,588 | + 3 |
| 1984-85 | 211,224 | - 8 |
| 1985-86 | 129,988 | - 38 |
| 1986-87 | 123,270 | - 5 |

Source : Central Board of Revenue, Government of Pakistan

Although the quality of locally manufactured batteries by integrated units are comparable to foreign products, their prices are on the higher side due to mainly high cost of production.

In addition to Chloride Pakistan Limited, Karachi and Atlas Battery, Karachi, there are several units engaged in manufacture of various parts and components of storage batteries. The annual production of storage battery parts for the last seven years is given in Table 4.3.

TABLE : 4.3. PRODUCTION OF STORAGE BATTERY PARTS

| Year | Production of Parts (No.) |
|---|---|
| 1979-80 | 163,000 |
| 1980-81 | 188,000 |
| 1981-82 | 244,000 |
| 1982-83 | 214,000 |
| 1983-84 | 220,000 |
| 1984-85 | 193,000 |
| 1985-86 | 174,000 |
| 1986-87 | 214,000 |

Source : Central Board of Revenue, Government of Pakistan.

It can be noted from the above Table that while there was an increase in the production of local parts and components including plates, separators, etc. upto 1981-82 the decline started significantly after 1984-85 presumably due to the decrease in the number of batteries produced locally.

Import of Batteries and Battery Parts

At present storage batteries are also imported. The installed production capacity of storage batteries can meet the domestic requirements but small quantity mainly of specialized batteries has to be imported. Imports of storage batteries decreased from 30,155 valuing Rs. 13.17 million in 1981-82 to 5.556 valuing Rs. 20.15 million in 1985-86, showing an average decrease of 34 percent in terms of quantity per annum. Table 4.4 gives the time series data :-

Table : 4.4 Import of Storage Batteries

| Year | Quantity (Nos.) | Value (Rs. in million) |
|---|---|---|
| 1979-80 | 13,026 | 10.48 |
| 1980-81 | 4,479 | 7.55 |
| 1981-82 | 30,155 | 13.17 |
| 1982-83 | 17,087 | 29.52 |
| 1983-84 | 10,840 | 10.30 |
| 1984-85 | 2,075 | 14.05 |
| 1985-86 | 5,556 | 20.15 |

Source : Federal Bureau of Statistics, Government of Pakistan

As regards import of storage battery parts, it varied from 650 tonnes valuing Rs. 22.26 million in 1979-80 to 391 tonnes valuing Rs. 18.16 million in 1985-86 as per details in Table - 4.5.

Table : 4.5 Imports of Parts Storage Batteries

| Year | Quantity (Tonnes) | Value (Rs. in Million) |
|---|---|---|
| 1979-80 | 650 | 22.26 |
| 1980-81 | 445 | 19.01 |
| 1981-82 | 536 | 8.96 |
| 1982-83 | 333 | 11.58 |
| 1983-84 | 425 | 14.12 |
| 1984-85 | 585 | 15.45 |
| 1985-86 | 391 | 18.16 |

Source : Federal Bureau of Statistics,Government of Pakistan

Various types of storage batteries and their parts are normally imported from Germany, Japan, France, U.K. Bulgaria, Netherland etc.

## Raw Material

The Storage Battery Industry in Pakistan depends heavily on imported raw material. The major raw materials used in the production of storage batteries are lead and its alloys, scrap lead and sulphuric acid. Of these, only sulphuric acid is produced locally.

i) <u>Lead :</u> Basic raw material for production of storage batteries is lead, lead oxide and its alloys. Pure lead and its oxide is used in battery plates whereas antimonial lead of 4 to 9 percent is mainly used in manufacture of grids, straps and terminals of batteries. Pure lead is imported from which lead oxide is obtained by oxidation. Antimonial lead can be processed locally as reclaimed lead from scrap lead. There are several units in the country engaged in processing of reclaimed lead from scrap lead. Storage battery industry is the largest user of lead in the country. Lead is imported from China, Canada and USA. Other users of lead are the paint and ammunition industry.

ii) <u>Sulphuric Acid :</u> There are 9 units engaged in production of sulphuric acid in Pakistan with an installed capacity of 87,000 tons and there is no shortage in the local market. However, a small quantity of sulphuric acid is imported as laboratory chemical.

iii) <u>Parts and Components :</u> The finished storage battery consists of several parts and components i.e. containers, separators, lids, plates, poles, positive and negative terminals, connectors, vent plugs, stickers, etc. These parts and components are being produced locally as well as imported.

## Demand/Supply Position

Table 4.6 compares the demand and supply position of storage batteries in the Country.

Table : 4.6 Demand/Supply Position

| Year | Demand (No.) | Supply (No.) | | | Demand/Supply Gap | |
|---|---|---|---|---|---|---|
| | | Local Prod. | Imports | Total | No. | As % of T.Supply |
| 1982-83 | 308,000 | 224,050 | 17,087 | 241,143 | 66,857 | 27.7% |
| 1983-84 | 339,000 | 230,588 | 10,840 | 241,248 | 97,572 | 40.4% |
| 1984-85 | 373,000 | 211,224 | 2,075 | 213,299 | 159,701 | 74.9% |
| 1985-86 | 410,000 | 129,988 | 5,556 | 135,544 | 274,456 | 202% |

The local production and imports have gone down tremendously during the recent years, thus increasing the demand/supply gap. It is anticipated that most of this gap is largely met through illegal imports. It may however be mentioned that the installed capacity, if adequately utilized, should be able to meet the current demand. However this aspect needs to be further investigated.

# CHAPTER - 5

## BATTERY POWERED ELECTRIC BUS

Although the limitations of a battery operated vehicle are too obvious, specially in our context, the project for design and development of an Electric Bus was undertaken as a joint collaborative venture of the National Transport Research Centre (NTRC) with the National Institute of Power (NIP) under the Ministry of Science and Technology and the Punjab Road Transport Corporation, with a view to at least develop the 'vehicular parts' (mainly the DC Series Motor and speed control systems, charging equipment, etc.) indigenously (not done before) and depending on the economics of the 'power source' (battery or overhead electric supply) can be used advantageously at the time of need. Of all the vehicles, the 'Electric Bus' was chosen as it is the extreme dependence on HSD in the road transport sector which dictates our oil import bill and therefore a suitable replacement for HSD operated vehicles (mainly buses, trucks, etc.) would be helpful in effectively checking the demand of oil in the road transport sector.

An old PRTC Isuzu Internal combustion diesel Bus (44-passenger capacity) and with a GVW of 12,500 Kgs was selected for the prototype experiment. The bus was refurbished adequately and since in the Electric version, the d.c. series electric motor assumes the role of the I.C. engine, the controller that of the carburetter and the battery with cables of that of the of Fuel Tank and pipes, all the unnecessary parts were removed.

A D.C. series motor of 25 KW continuous rating was designed, and locally fabricated by the National Institute of Power (Fig.5.1). The salient features of the d.c. series motor for the desired vehicle characteristics were as follows :-

D.C. Series Motor

| | | |
|---|---|---|
| Rating : | Continuous : | 25 KW |
| | One - hour rating : | 50 KW |
| Rated Voltage : | | 240 Volts D.C. |
| Rated Current : | | 110 Amps. |
| Max. Speed : | | 2000 rpm ( 40 Kms /hour) |
| Cooling : | | Induced fan (separate by two blowers each of 120 watts (12 volts, 10 amps) |
| Transmission : | | Through gears (1st, 2nd & 3rd) |
| Maximum Climbing gradient : | | 30% (1st gear) |
| Continuous Climbing : | | 10% gradient (2nd year) |
| Speed Control : | | D.C. to D.C. through thyristors 0-240 volts (current upto 210 Amps) |

A comparison of the broad features with other electric buses in Table 5.1 will indicate that the D.C. Series motor was of a very modest power rating.

The battery requirements were estimated to be 144 batteries each of 6 volts and 200 AH capacity with a total weight of about 4,200 kgs. However the developed d.c. series

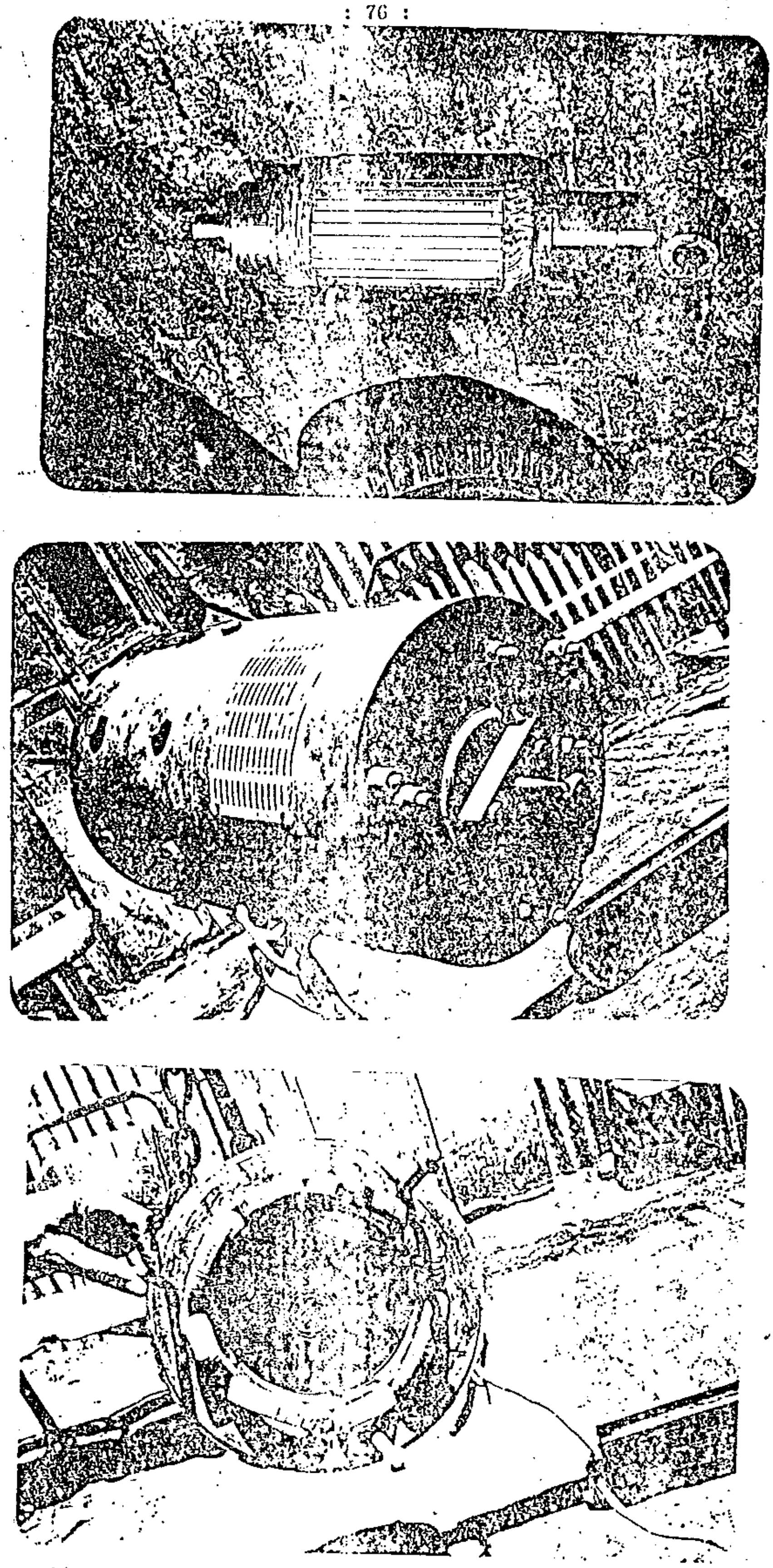


Fig. 5.1. D.C. Series Wound Motor

TABLE : 5.1 Characteristics of source of Battery Powered Electric Buses

| Country | Bus | Gross Vehicle Weight (Kg) | Motor Type | Motor Continuous (KW) | Motor Peak (KW) | Battery V | Battery Ah | Range (Km) (urban route) | Maximum speed (Km/h) | Acceleration upto 40 Km/h ($m/s^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. |
| U.K. | Silent Rider | 15,750 | d.c. series | 72 | 160 | 330 | 329 | 60* | 65 | 1 |
| U.K. | Lucas | 9,874 | d.c. | 97 | | 360 | 220 | 64* | 80 | 0.89 |
| U.K. | Crompton-DTI | 9,800 | d.c. series | 18 | | 220 | 376 | 55 | 35 | 0.34 |
| USA | Electro-bus | 7,800 | d.c. series | 37 | | 72 | 650 | 64 | 55 | 0.79 |
| Japan | Osaka Bus | 13,745 | d.c. series | 70 | 154 | 384 | 350 | 82* | 60 | 0.74 |
| Germany | Elektrobus OE 302 | 19,000 | d.c. separately excited | 115 | 150 | 380 | 275 | 60* | 70 | 0.66 |
| Germany | MAN-SL-Electro-bus | 17,600 | d.c. | 118 | 174 | 360 | 455 | 100* | 68 | 0.53 |
| Germany | DUO Bus | 18,000 | d.c. separately excited | 75 | 150 | 360 | 210 | 40* | 70 | 0.69 |
| France | AS09 Electro-bus | 10,020 | d.c. series | 27 | | 192 | 576 | 75 | 50 | 0.46 |
| France | Alsthom-RATP Electro-bus | 9,300 | d.c. series | 18 | | 220 | 376 | 30 | 60 | 0.44 |
| Pakistan | Electric Bus (under development) | 12,500 | d.c. series | 250 | 50 (One hour) | NT | NT | NT | NT | NT |

NT - Not tested on Batteries

motor was never tested on battery operation because the lead acid batteries that are locally available are of the SLI type and are not suitable for deep cycle operations and are known to have a very limited cycle life of only about 50-100 cycles. Besides the infrastructural requirements for charging of the batteries, etc. was considered to be very un-wieldy considering the extreme limitations of the available battery system. In terms of cost, the 50-100 cycle life batteries would have cost about Rs. 175,000/- and in view of the limited life and the battery weight/range problem, the bus would have operated on only about $\frac{1}{4}$th of its normal route only for a few days on a given set of batteries before these batteries would have required replacement.

However, a limited driving test was carried out using the overhead supply through a rectifier system in the PRTC yard. The bus was, however, dismantled after a limited test for its use as a conventional diesel bus.

Since the design, development and fabrication of the d.c. series motor and speed control circuits, charging equipment, etc. form part of a separate report to be prepared by the NIP, the details have not been included. However, the limited experiment has proved that the vehicular system parts of an electric vehicle can be locally designed, developed and fabricated. Further work has therefore been held in abeyance to await the availability of a proper battery which can overcome the problem specially of range and weight

TABLE - 6.1 COMPARISON OF MASS AND VOLUME OF AN ICE VERSUS BATTERY SYSTEM

| Engine Type | Fuel System | Mass (Kgs) | Volume (Litres) |
|---|---|---|---|
| I.C.E. | Hydrocarbon fuel | 40 | 55 |
| Electric Battery Powered | - Lead Acid | | |
| | - Traction | 4,300 | 2,000 |
| | - Flat Plate | 2,500 | 1,800 |

Thus the lead acid battery as a store of energy has about 100 times weight disadvantage and about 50 times volume disadvantage over petrol.[4]

Expressed in another way since all vehicles consume energy to move, a small family car with a laden weight of a ton would consume an energy of 10 KWH or 10 electricity units to move for 48 Kms (30 miles). 10 KWH is stored in one fifth of a gallon of petrol but as four fifths of the energy in a petrol engine is wasted, one gallon of petrol weighing about 3.8 Kgs (8.5 lbs) to derive 10 KWH would be required for 48 kilometers (30 miles) range. To store 10 KWH in an electric lead acid storage battery would require about 345 Kgs (750 lbs) of battery occupying 0.2 cubic metre 6 cubic feet. This imposes constraints on the car since the battery mops up volume and consumes about half of its own substance in transporting itself about. Thus petrol as an energy store is at least 90 times lighter and takes 37 times less space than the lead-acid battery.[14]

(2) Refueling/Recharging Time/Capability

The infrastructural requirements (Petrol Pumps) for the re-fueling of a conventional ICE Car are available almost every where and a full Petrol tank has a range of about 480 Kms (300 miles) which is installed in a matter of few minutes. From an electric socket outlet rated for a 3 KW output and allowing for the inefficiencies of the charging process and of the electric vehicle, it would take four hours to instal 30 miles of range into an electric vehicle, whereas it takes one tenth of a minute for a gallon to flow into a car which allowing for the petrol car inefficiencies tantamount to installing a 30 mile range. Hence the electric socket is putting in range at the rate of 7.5 miles per hour whereas the petrol pump installs range at the rate of 18,000 miles per hour. Expressed in another way a petrol pump which delivers petrol at the rate of 10 gallons per minute is equivalent to a 30 MW Power source for a battery system.

The electric vehicle thus carries a very limited energy store equivalent to about one gallon of petrol which can be only re-filled over a period of several hours. The ability to install range in an electric vehicle using a 3 KW (i.e. 13 amp.) outlet is thus about 2,400 times slower than that of the petrol pump. To achieve parity is impossible and an attempt to improve it by battery exchange will be prohibitively expensive, besides posing problems of ownership for the battery exchange system, the capital tied up in un-used batteries and a large labour force.

(3) Maintenance Requirements

Although Battery operated EVs are claimed to be 'maintenance free' the following factors which are important and deserve utmost care for obtaining the desired performance from the installed battery (Pb Acid in this case) and to avoid 'pre-mature' failure of the battery system, would highlight the demanding requirements of manpower and equipment:[7]

(1) Right Amount of Charge : The battery must be given the right amount of charge. Checking the charging equipment and behaviour of the cells periodically is very important to ensure that :-

(a) The charger is giving its full rated output.

(b) The relay operates at the specified voltage.

(c) The period between the relay operating and the end-of-charge is correctly adjusted.

(2) Undercharging : Undercharging over a long period can do irreparable damage to a battery. The residual lead sulphate, particularly in the negative plate, expands and blocks off the previously porous sponge lead, thus reducing the capacity of the battery. The best protection against undercharging is to take specific gravity readings after the normal recharge has been completed.

(3) Overcharging : Overcharging can equally have an adverse effect on a battery's life and efficiency, and it may not be

so immediately obvious. This would require noting the battery's voltage and charge current from the charger's ammeter, and comparing it with the recommendations in the battery manufacturer's instruction book.

(4) Overdischarge : A battery should never be discharged over 80 percent of its capacity. The specific gravity of the electrolyte reflects relatively accurately how many ampere-hours have been taken from a cell on discharge. Readings of a pilot cell must be taken immediately the battery has finished work. If the specific gravity falls below 1.140 the battery is either being over discharged or there is a failutre in the battery.

(5) Correct Topping up of Cells : Most of the batteries have to be topped-up for their water levels manually, and besides problems of spillage is quite time consuming as well. Low electrolyte levels will cause oxidation, sulphation of the exposed plates, and high battery temperature on charge, due to the reduced electrolyte volume while high levels will cause the electrolyte to flood the tops of the cells during the gassing on charge with resultant loss.

Topping up should be carried out before charging, so that the water which is added is thoroughly mixed with the electrolyte during the recharging. Presently Batteries with automatic topping up devices are available, and require relatively little operator attention.

(6) Safety and Maintenance : Never use a naked flame near a battery, particularly during charge or shortly after it has been charged, as the gases given off by a battery ($H_2$ and $O_2$) can ignite and cause a serious explosion.

(7) Cleaning and Drying of Cells, trays and containers :

When a battery top is wet, current will leak between the terminals, causing a loss of capacity on open circuit, and terminal corrosion.

Small amounts of acid can be sprayed onto cell tops during charging, and if water is spilled onto them, it causes this acid to spread. This creates a film of acid over the cell tops, which can cause the battery to deteriorate as it creeps over the edges of the cell boxes.

For avoiding corrosion, any remaining acid should be neutralised with a solution of water and sodium bicarbonate or sodium carbonate, or with dilute ammonia. Further protection would include covering the affected area with petroleum jelly.

Battery trays should be washed-down with one of the above mentioned solutions occasionally, and coated with acid proof paint when they are dry.

(8) Covering 'exposed' metal with petroleum jelly : This will avoid corrosion and the short circuiting caused by the effects of acid-spillage.

(9) Addition of acid to cells : When acid has been spilled and needs to be replaced, special precautions should be taken to avoid chances of spillage. Under normal operating conditions, only water is lost from cells, through the natural evaporation and electrolysis caused by gassing during charge. It is this water which is replaced during topping-up.

(10) Filling-plugs and connections : Filling plugs should be removed only to top-up or take specific gravity readings. Connections should be kept tight as these can cause a battery to operate less efficiently, or to arc and be a safety hazard.

(11) Operating Temperatures: If a battery is to be operated in extremely high temperatures (such as tropical climates) or extremely low temperatures (such as cold stores), advice of the manufacturers must be obtained for the special operating methods which are necessary.

(12) Specialized Training: Specialized training is necessary for maintenance personnel in operation, maintenance, of batteries and chargers.

(4) Energy Conservation

An electric vehicle does not make out a case on energy conservation grounds as it even needs somewhat more amount of energy to propel it as its conventional ICE equivalent.[14,15,16]

The stages from crude oil at the refinery to useful work at the vehicle wheels for a conventional internal combustion engined vehicles may be described as a series of efficiencies as follows:-

| | |
|---|---|
| Refinery and distribution | : 82 percent |
| Thermal efficiency of engine | : 25 percent (petrol); 35 percent (diesel) |
| Transmission | : 90 percent |

The overall gross conversion efficiency is thus 18 per cent (0.8 x 0.25 x 0.9) for petrol engines and 26 percent for diesels (0.82 x 0.35 x 0.9). Since in urban conditions up to half the energy supplied at the wheels is dissipated in braking, the range of overall gross efficiency for the internal combustion engined vehicles becomes 9-18 percent for petrol and 13-26 percent for diesels.

For a battery electric vehicle, from the fuel burned in the power station to useful work at the wheels, and taking even the improved lead/acid battery in the light goods vehicle for example, the equivalent figures for efficiency are :

| | Usually | | |
|---|---|---|---|
| Power station generation | 30 Percent | 40% | for a large modern power station working as base load |
| Transmission from power station | 93 Percent | | |
| Battery Charge/Discharge | 80 Percent | | |
| Electric motor, controls, transmission | 70 Percent | | |

The overall gross efficiency thus ranges from 16 to 21 percent ( (0.3 x 0.93 x 0.8 x 0.7) and (0.4 x 0.93 x 0.8 x 0.7) ). Out of this about half the energy would be dissipated in braking, but even if it were possible to provide regenerative braking at 50 percent efficiency, the range of overall gross efficiency becomes 12-16 percent and 16-21 percent respectively. But the battery vehicle will be heavier by at least 20 percent for the same payload capacity as an I.C.E. light goods vehicle and therefore its effective overall efficiency range will thus be 10-13 percent (13-17 percent).

Thus, compared with the range of efficiencies for both petrol and diesel operated internal combustion engines, it can be seen that there is little justification in looking to the battery vehicle to save energy. Also the battery vehicle usually has difficulty in meeting the heating load of a passenger car or bus without auxiliary heating or a drain on the main batteries, and oil heaters, etc. need to be provided. This load is of course readily provided for in the internal combustion engine vehicle from waste engine heat.

(5) Infrastructural requirements

Most of the current literature assumes the existence of appropriate infrastructure for charging the batteries. This is a very naive assumption specially so in the case of a large scale introduction of electric vehicles which would become necessary in the case of increasing oil crises or if EVs were to be operated on a scale to produce visible impact on the import of oil. Naturally this would also require that cheap sources of electricity are available in the country to provide the requisite electricity for the charging of batteries.

With the increase in the concentration of vehicles in one spot, it will be necessary to install special power supplies for charging of the batteries. The problem would be particularly acute for urban buses. For example in a city garage containing 100 buses, a very modest number, each of which would require about 300 KWH of electricity, the total requirement would be of 30 MWH. Spreading this load over 6 hour recharge time, a 5 MW power supply to the garage would be required[4]. This might be provided by a standard 11 KV line and each bus would require a 50 MW recharging point.

It may be pointed out that this does not take into account the spare battery exchange systems which would be necessary in a 'real world situation' for operating the bus. Assuming a range of 80 Kms per charge per bus, at least 2 spare battery sets would be necessary for an average daily bus operation of about 240 Kms. If the charging requirements for these batteries is also taken into account the power requirements would be 15 MW for a fleet of 100 Electric buses.

Clearly, installing these power supplies in an existing city bus depot is a major electrical engineering undertaking. Besides so much power may not be easily available at the 'local level' even during the night time period for a continuous period of 6-8 hours. Problems will arise from the confined space at most of the existing garages/depots and the over-all cost will be high for acquisition of surrounding land specially in the urban context. Many existing garages may even prove to be unsuitable and it would then be necessary to design and build new garages.

It may be of interest to note that at the current tariff strcuture of WAPDA for industrial supply at 66KV and 132 KV to loads above 5 MW, the fixed charge per KW per month are Rs. 96 per month plus Rs. 0.41 per KWH of energy consumed. The following simple calculations in Table 6.1 show that the energy charges per Km would be Rs. 1.70. Although this does not take into account the effect of other associated infrastructural costs it is about 40 percent more as compared to the present diesel cost per bus km of about Rs. 1.20. In terms of the total monthly energy charges, the diesel cost would be only about Rs. 0.864 million as compared to the total electricity charge of Rs. 2.547 million.

TABLE : 6.1 MONTHLY ELECTRICITY CHARGES FOR 100 BATTERY POWERED ELECTRIC BUSES USING PRESENT WAPDA TARIFF FOR INDUSTRIAL SUPPLY AT 66 KV AND 132 KV

| | Rs. |
|---|---|
| Fixed Charges @ Rs. 96 per KW/month for 15 MWH = Rs. 96 x 15,000/- | 1,440,000 |
| Energy Charges @ Rs. 0.41 per KWH for 3 x 300 x 100 x 30 KWH/month including 2 spare battery sets per bus = Rs. 0.41 x 3 x 300 x 100 x 30 | 1,107,000 |
| - Total monthly energy charges for 2700 MWH | 2,547,000 |
| Energy Charge per KWH | 0.943 |
| Energy Charges per Km per Bus (@ 1.8 KWH per Km) | 1.70 |

The situation for commercial goods vehicles which are considered to be the prime market sector for EVs for urban use is likely to be intermediate between that of domestic garages and bus garages. Compared to buses, the smaller batteries and longer times available overnight for recharging are favourable factors, while the garage congestion is often less severe. However even in this case, the cost element of providing the recharge facilities are going to be fairly substantial and cannot be overlooked.

It may, however, be pertinent to point out that while the versatility of ICE vehicles is on account of the existence of liquid fuel, the above mentioned comparative analysis with reference to an ICE vehicle may not be construed to generate a kind of complacence towards the development of alternative sources of energy for the road transport sector as in the case of extreme scaracity of fuel, we will have to reorganize our demands and find alternatives in the form of other than ICE vehicles say a battery/overhead powered electric vehicle to provide for the barest essential mobility.

# CHAPTER - 7

## CONCLUSIONS AND RECOMMENDATIONS

A battery powered electric vehicle is handicapped mainly on account of the Batteries currently available. The serious handicaps as described earlier are briefly as follows :-

(1) Mass : 100 times weight dis-advantages as compared to liquid fuel. Battery weight almost equivalent to the Pay Load and upto 32 percent of the gross vehicle weight.

(2) Volume : 50 times volume dis-advantage as compared to liquid fuel.

(3) Range : Limited range only about 1/8 th of what could be available in an I.C. vehicle in one refill/charge.

(4) Refuelling/Re-charging Time : About 2,400 times slower for 1/8th of the range. Battery Exchange option besides posing problems of ownership and a large labour force for changing battery racks is extremely capital intensive with substantial capital tied up in un-used batteries.

(5) Energy Conservation : No overall advantage offered by an electric vehicle. The overall efficiency of an electric vehicle being from 10-17 percent compared to 9-18 percent for petrol vehicle and from 13-20 percent for diesel vehicle.

(6) Vehicle/Battery Costs : Not in production and therefore realistic cost difficult to assess. However, considered to be at least 1.4 times more expensive to buy as compared to their diesel equivalents with all its limitations.

As regards operating costs the extreme limitations of range and accurate data on Battery Life, etc. preclude any straight forward comparison.

(7) Gradient : Poor performance an gradients. Even difficult to climb 12% gradient in a purpose built vehicle.

(8) Cycle Life : An SLI battery performs very poorly with cycle life of only about 50 to 100 cycles.

A traction battery (tubular type) performs better with claimed cycle life of about 1,000 cycles but poor in terms of power density and hence poses problem on gradients and during acceleration.

(9) Operation Time/Availability : Due to limited range and given operating speed, the overall average operation time per vehicle is typically in the neighbourhood of 1- 1.25 hours per day before the batteries need to be fully recharged. The daily kilometers operated is usually about 30-40 kilometers per vehicle per day.

(10) Maintenance : The much publicized slogan of lesser maintenance in EVs (due to smaller number of moving parts) need to be seen in the light of the Denmark Demonstration Project with 5 Fiat Electric Vehicles where the 'idleness frequency' was recorded to be 20% as compared to 3% with other types of vehicles[6]. Also the battery maintenance requirements in terms of care and supervision during charging, frequent check-ups and precautions necessary to minimize damage due to exhaust gases (hydrogen and Oxygen)during charging and acid spray, etc. to ensure safe and life long operation seem to be grossly under estimated both in terms of manpower and special equipment required.

(11) <u>Infrastructural Requirements :</u> Current literature/work is almost silent and does not take into account the infrastructural requirements which would be extremely capital intensive if large scale conversion is desired for a visible impact. Converting only about 100 buses as battery powered vehicles would require about 90 MWH of electricity on a daily basis for operating about 240 kilometers as is normally performed by an equivalent diesel bus. This would require a 15MW Power Supply to the garage in an urban set up which would be a major electrical engineering undertaking. The total electricity charges alone, on a monthly basis, at the current tariff structure of WAPDA for industrial supply would be about Rs. 2.6 million compared to about Rs. 0.8 million on diesel.

All these problems pose a major technological challenge and a break through covering all forms of transport can only be expected if a cheap, dependable, long life, light weight maintenance free, high power and high energy density battery with minimal charging time coupled with the development of 'cheap sources' of electricity for charging the batteries and a network of 'refueling' stations is available at convenient places. However considering the pace of development in the battery technology, development of such a battery would not be readily achievable.

On a short to medium term basis, the battery powered vehicles can find application in 'off-road' applications which normally do not require long range and only intermittent use e.g :

- in-plant load carriers,
- in-plant personnel carriers,
- golf-carts,
- Forklift trucks,
- Airport /Railway Terminal Use Vehicles, etc.

But it is obvious that such limited off-road use application would at the best be on a very limited scale and not of any help in achieving the stated objective of reducing dependence on oil.

The next possible application could be as a range limited vehicle for urban use. However it would be necessary to carry out a detailed trip pattern distribution study so as to assess the market potential of such range limited vehicles purely in the urban context.

A word of caution would be necessary here as the whole issue of an alternative source of energy for the road transport sector needs to be seen for the scenario when the oil reserves would be depleted. A valid comparison for such a situation would therefore be a comparison of the battery operated vehicle with the other alternative options available when there would be no oil and hence oil using vehicles. Since there could be flexibility as regards the source of power in an Electric Vehicle (Battery/Overhead, etc.) it would be worthwhile to keep full track of the developments in this field and to have a complete access to the EV technology so that we are not caught un-aware in the case of an eventuality.

# R E F E R E N C E S


1. Economic Survey 1986-87
Economic Advisor's Wing,
Ministry of Finance,
Government of Pakistan,
Islamabad, June, 1987

2. Weingart, Jerome M.
Establishment of a High Technology Research and Development Institute for Renewable Energy Resource Development in Pakistan,
UNDTCD Project Pak/85/X01, January, 1987

3. Energy Year Book 1986
Directorate General of New and Renewable Energy Resources, Ministry of Petroleum and Natural Resources, Islamabad

4. Johannes Jensen, Peter McGeehin and Ronald Dell, Electric Battries for Energy Storage and Conservation-an application Study, Odense University Press, Denmark,1979

5. Samuel, John, Preliminary Study into Electric Vehicle Technology for application in developing countries, International Foundation for the Development of NEW AND EMERGING SCIENCES AND TECHNOLOGIES, UK, August, 1986

6. Nissen Ole Stig, Demonstration Project with 5 electric vehicles in Odense, Denmark, Final Summary Report for Contract EE/85/80, April 1986

7. Understanding Motive Power Batteries and Chargers, Chloride Motive Power, England Publication MPUK4 10M270/1/82.

8. Waters M.H.L. and Porter J., A review of market prospects for battery electric road vehicles - part 1, Department of the Environment, TRRL Laboratory Report 630, Crowthorne, Berkshire, 1974 (Transport and Road Research Laboratory)

9. Johannes, Jensen and Sorensen Bent; Fundamentals of Energy Storage, A Wiley - Inter Science Publication, John Wiley and Sons, New York, 1984.

10. Fink Donald G., Carroll John M., Standard Handbook for Electrical Engineers, 10th Edition, 1969 Mc-Graw Hill Book Company.

11. Industrial Research Service, Pakistan Storage Batteries in Pakistan, IR-Report No. 312, December 20, 1985

12. Industrial Research Service, Pakistan, Storage Batteries in Pakistan-II, IR-Report No. 313, December 30, 1985

13. New Integrated Plant for Automotive Batteries in the Daily Muslim, Islamabad July 30, 1987

14. Proceedings of a Symposium on Battery Electric Road Vehicles, held at the TRRL 8th November, 1973, Department of the Environment, TRRL Supplementary Report 54 UC, Crowthorne, Berkshire, 1974

15. Jensen, Johs; Lundsgaad, Jorgen S, and Perram, Carol M. Electric Vehicles for Urban Transport, Odense University Press, Denmark 1980

16. Dell, RM and Jensen J., Implications of Future Large-scale use of Electric Vehicles in Europe. United Kingdom Atomic Energy Authority Harwell AERE-R 9958, October, 1980

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