Electrical Equipment - Course 230.2

STATION BATTERIES AND BATTERY CHARGERS

1. OBJECTIVE

The student must be able to:

1.1 State the purposes of:

(a) batteries and,
(b) chargers.

1.2 State the purpose of each part of a battery.

1.3 Describe the indications and tests which show the battery and charger are operating normally.

1.4 Describe:

(a) the indications and tests which show the battery and charger are operating abnormally.

(b) the operator actions to be taken to correct the abnormality.

(c) the consequences of allowing a battery to continue operating abnormally.

1.5 For a lead-acid battery and its charger, state:

(a) the safety precautions.

(b) the consequences of violating these safety precautions.

2.0 INTRODUCTION

In Nuclear Generating Station and heavy water plants, batteries are provided to ensure that the Class 1 system has a "No break" supply. This lesson describes the lead acid (Antimony and Calcium based) batteries that are used and the precautions that must be taken. It explains how the batteries are charged under float and equalize conditions.

3.0 THE DC SYSTEM SUPPLIED BY THE BATTERIES

The 250 V station batteries are maintained in a fully charged state. This ensures that **at all times** there is Class 1 power available for controlling or shutting down the plant. Figure 1 shows that each 250 V Class 1 dc bus has two supplies. Under normal operating conditions, the loads on the bus are fed from the battery charger and the battery **"floats"**, ie, it is kept at constant voltage and gives no output. In the event of a charger failure or a failure of supply to the charger, the load on the Class 1 bus will be carried by the battery until it is fully discharged. In an emergency, the battery has sufficient Ampere-hour (Ah) capacity to:

(a) operate safety mechanisms,
(b) shut down the plant safely,
(c) provide emergency lighting.

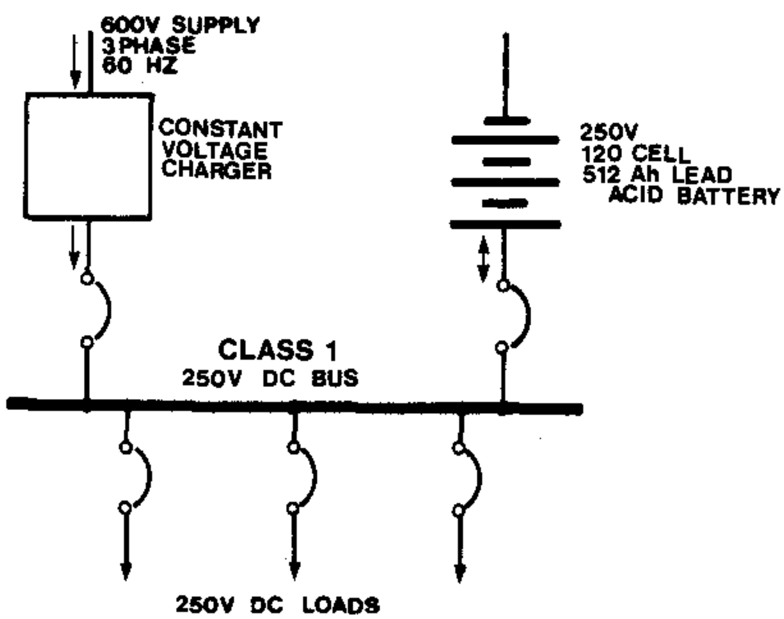

Figure 1: Diagram Showing the 250 V Bus, Battery, Charger and Loads.

4.0 BATTERY CONSTRUCTION AND MAINTENANCE

4.1 Lead Acid Batteries (General)

Each cell of a lead acid battery consists of several alternate positive and negative plates which are insulated from each other with porous plastic spacers. The plates and spacers are inserted in a transparent glass or plastic case. Figure 2 shows a section of a lead acid cell. For simplicity, only one positive and one negative plate are shown.

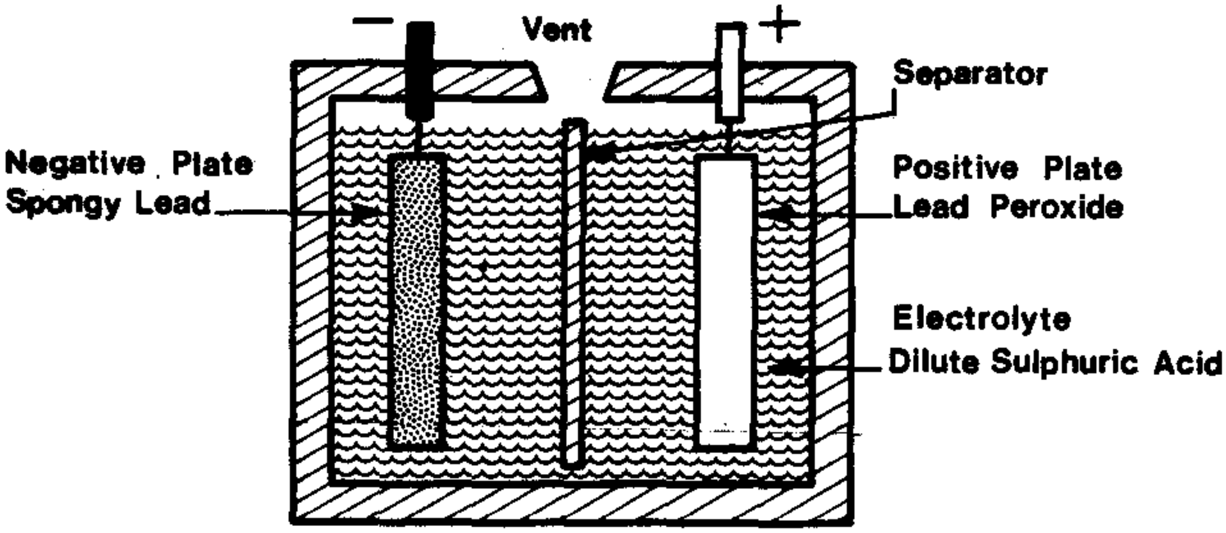

Figure 2: Sectional Diagram of a Lead Acid Battery having Two Plates.

The plates are made from cast lead grids which are then covered with paste. The positive plate is covered with a brown lead peroxide (PbO_2) paste. The negative plate is covered with a spongy lead (Pb) paste. The plates are immersed in a dilute (50% concentration) sulphuric acid solution which is called the **electrolyte.** The following reversible chemical reaction takes place:

$$PbO_2 + Pb + 2H_2SO_4 \rightleftarrows 2PbSO_4 + 2H_2O$$

Battery charged Battery discharged

From the above it can be seen that a charged battery has an electrolyte consisting of H_2SO_4, while a discharged battery has an electrolyte consisting of water. In practice, when discharged, the plates do not convert all the sulphuric acid to water and the electrolyte still contains a significant quantity of sulphuric acid.

During charging and discharging, some of the water in the electrolyte is broken down to form Oxygen (O_2) and Hydrogen (H_2). (The Oxygen and Hydrogen escape into the atmosphere forming a potentially explosive mixture, see section 5.0). As the water breaks down, the electrolyte level falls and distilled (demineralized) water must be added to each cell to bring the electrolyte back to the specified level. Failure to add water will cause the electrolyte to become two strong; this will:

(a) reduce cell life
(b) reduce cell ampere-hour (Ah) capacity.

4.2 Antimony and Calcuium Based Cells

The difference between an antimony based lead acid cell and a calcium based cell, is that with the antimony types, the grids are cast from a lead-antimony alloy, while with the calcium types the grids are cast from a lead-calcium alloy. The lead-calcium types are a newer development and have the following advantages over the older lead antimony types. These advantages are:

(a) less water (typically one fifth) has to be added to keep the electrolyte up to its level.

(b) equalizing charges need to be done less frequently (or in some cases not at all).

(c) they have a slightly higher terminal voltage per cell, (see text).

(d) longer life, (25 versus 16 years).

(e) much lower float current, (appoximately one sixth).

(f) produce less H_2 and O_2 gases.

Figure 3 shows that as a lead acid antimony based cell discharges, the specific gravity of the electrolyte falls from 1.220 to 1.150. At the same time the on load voltage per cell falls from 2.15 V to 1.75 V. These figures are correct at 25°C.

In the case of a calcium based cell, the gravity of the electrolyte falls from 1.250 to 1.180 and at the same time the on load voltage per cell falls from 2.25 V to 1.8 V. Again, the figures are correct at 25°C.

By taking readings of specific gravity and voltage for each cell, the state of charge in each cell can be reliably determined. For example, if a lead antimony cell has an on-load terminal voltage of 1.95 V and a specific gravity of 1.185 then from Figure 3 it can be seen that the cell is half charged. It is advisable to take the on load terminal voltage, because when on no load, the cell voltage tends to rise to the fully charged value.

Failure to regularly check individual cell voltages and gravities can, in an emergency, result in the battery being unable to deliver the required output.

Lead calcium cells, when being charged or discharged, produce less gas than the antimony types. With less gassing, there is less mixing of the electrolyte and during charging the heavier sulphuric acid tends to fall to the bottom of each cell and takes about four weeks to diffuse through the cell. Therefore, when taking specific gravity readings of lead calcium cells, the hydrometer nozzle inlet must be inserted at least half way down the cell.

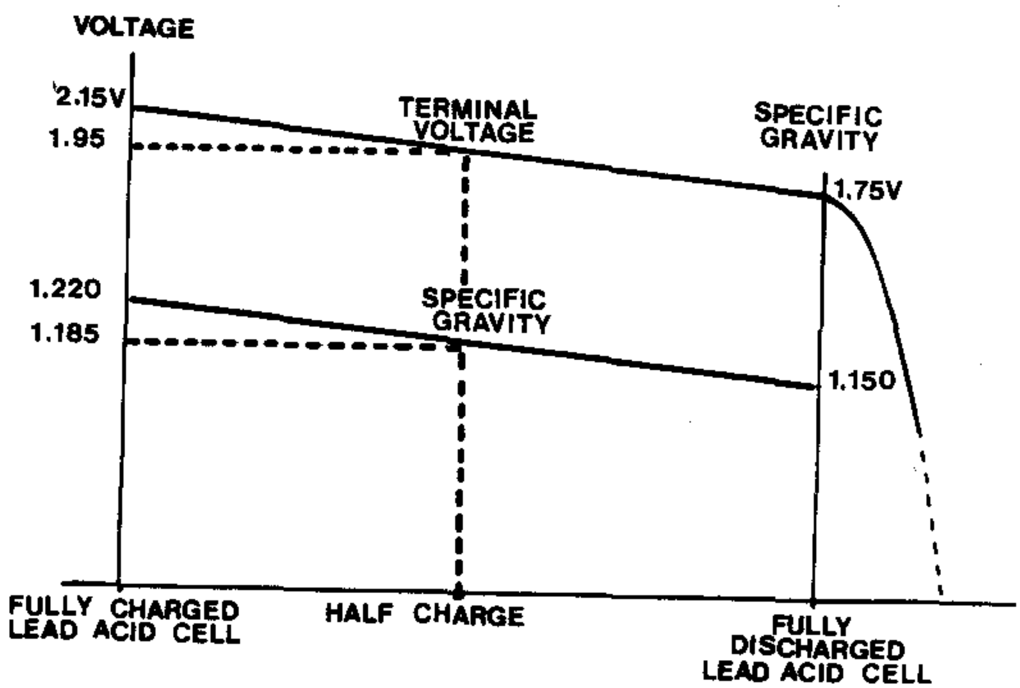

Figure 3: Curves of Terminal Voltage and Specific Gravity for a Lead Acid Cell (Antimony).

It should be noted that the terminal voltage and specific gravity are temperature dependent. Table 1 gives examples of the variations of specific gravity with temperature.

Temperature	Specific Gravity Per Cell	
	Antimony	Calcium
15°C	1.226	1.256
20°C	1.223	1.253
25°C	1.220	1.250
30°C	1.217	1.247

Table 1: Showing How, For a Fully Charged Lead Acid Cell, Specific Gravity Varies With Temperature.

When taking readings of specific gravity at temperatures which are significantly different from 25°C, the necessary corrections must be applied. Because the battery room is kept at 25°C ±5°, temperature corrections are not ususally applied to voltage measurements. Very low temperatures affect the chemical action within the cells and will seriously affect the amount of electrical energy that can be taken out of the battery.

5.0 HAZARDS AND PRECAUTIONS WITH LEAD ACID BATTERIES

There are three safety hazards associated with lead acid batteries. The hazards are:

(a) Gases

It is **essential** that the ventilation system is operating at all times. It must be checked before anybody enters a battery room. Oxygen and hydrogen are given off from the electrolyte during charging and discharging. If these gases are allowed to accumulate, an explosion can result. No smoking or naked lights or flames are permitted in a battery room.

(b) Acid

To avoid acid burns, before any work is done with acid - and this includes taking specific gravity readings - the proper protective clothing must be worn. A facemask or goggles are required to protect the eyes and an apron and gloves are required to protect the body. In addition, there must be a supply of water available to wash off any acid that may come into contact with the eyes or skin.

Acid spills must be immediately cleared up and the battery room must be kept free of all debris.

(c) Electricity

It is often forgotten that a battery contains a large amount of stored electrical energy. Station batteries have bare exposed terminals and bare intercell connectors. Short circuiting a battery will produce large currents. These currents can damage the battery and cut off the Class 1 supply. Any person involved can be burned or electrocuted. Therefore great care should be taken to use insulated tools. In addition, never take aluminum ladders into a battery room.

6.0 AGING OF LEAD ACID BATTERIES

Lead acid batteries, like any piece of electrical apparatus, have an economic life. In Hydro experience this is about 15 to 25 years. This life will be shortened by poor maintenance and/or poor operation. The main factors which shorten the life of a battery are:

(a) Overcharging

This can be due to too high a charge rate, ie, too high a charging current or due to too high a charge voltage. In both cases the manufacturer's or the station's recommendations must be followed.

(b) Discharging at Too High a Rate

Too high a current discharge rate will shorten the life of a battery. Again the recommended figure should not be exceeded.

(c) Excess Temperature

During charging and discharging, a battery's temperature will increase. It must not be allowed to exceed 43°C.

All of the above will shorten the life of a battery by causing the paste to become detached from the plates and fall to the bottom of the cells. Figure 4 shows a cell where the paste has fallen to the bottom of the case. The sediment has built up until it has touched both plates. When this occurs, the sediment forms a short circuiting path and the battery will no longer hold a charge.

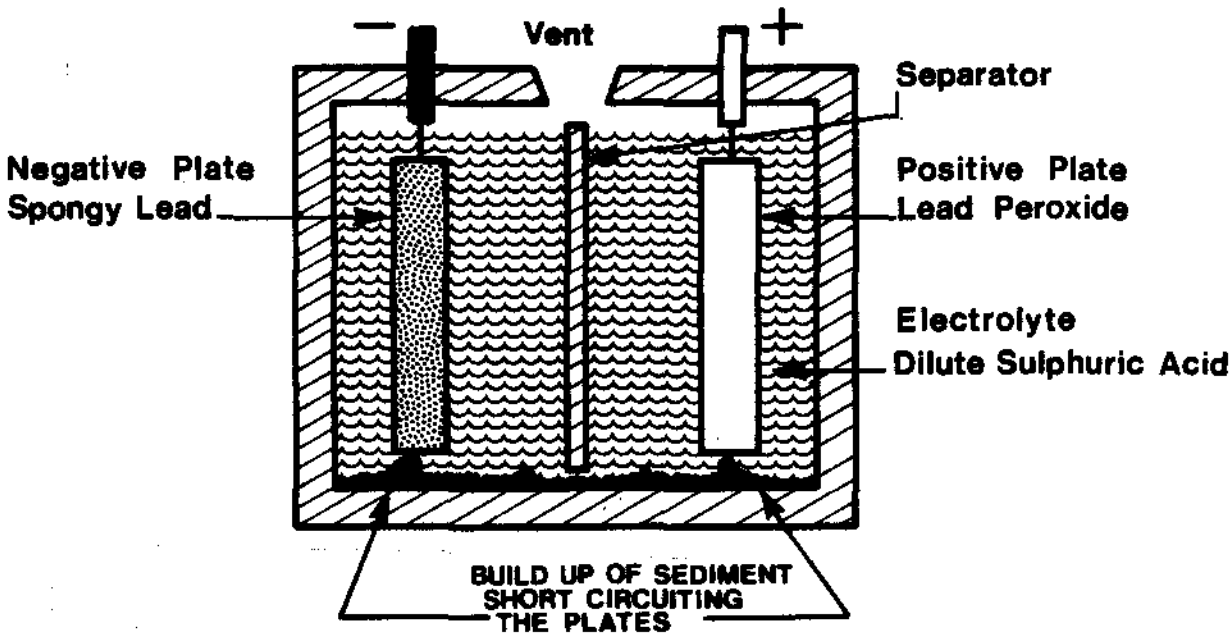

Figure 4: Diagram Showing How the Plates are Short-Circuited by Sediment.

The lead grids may also break if a battery is charged at too high a rate or if the electrolyte temperature of 43°C is exceeded.

The cases of each cell are made from transparent material. This allows a visual inspection to be made of the plate conditions, electrolyte level, gassing state, and sediment level. Frequent inspections will show deterioration and action can then be taken to prevent cell or battery failure.

8.0 CHARGING AND DISCHARGING OR BATTERIES

8.1 Float Charge

Normally, the station lead-acid batteries are "floated" across the dc busbars, and the load is supplied by the charger. If the charger fails, the battery carries the load until the charger is restored to service.

While battery is being recharged, the charger has to supply the load current as well as the battery charging current. Battery charging current is called float charge. It has two purposes.

(i) Charge the battery once it is used.

(ii) Supply the makeup charge to maintain the battery at its charged state. Makeup charge is required because the internal leakage in the battery occurs at all times.

8.2 Equalizer Charge

The voltage across the battery bank is the algebraic sum of all the individual cells connected in series (120 cells for 250V system).

However, no two cells are exactly alike due to the manufacturing material, temperature and specific gravity variations, therefore one cell voltage may be higher than the other cell. This means normal terminal voltage of a battery bank does not guarantee that each individual cell voltage is also normal because the cells with higher than normal voltage will mask the cells with lower than normal voltage. If a cell does not have full charge voltage it is not fully charged and the battery bank will not deliver rated output. Refer to the battery cell terminal voltage and charge curve, Figure 3.

To overcome this inconsistency of state of charge in the individual cells in a battery bank, whole battery bank is intentionally overcharged periodically under controlled conditions. This brings the weak cells to the required charge level and over charges the normal cells to some degree. This charge given to the battery is called an equalizer charge. The weak cells are referred to as "pilot" cells. Pilot cell is the one which had lowest specific gravity reading in the previous maintenance checks on the battery bank.

During the equalizing charge the battery and bus voltage is above the rated value. Care will have to be taken to ensure that the connected equipment is not damaged due to this excess voltage.

Equalizer charge should be stopped if any of the following conditions exist:

(a) The voltage per cell exceeds 2.33 V.

(b) The specific gravity of any cell exceeds 1.240.

(c) The temperature of any cell exceeds 43°C.

When the overcharge is completed, every cell will have a similar voltage and specific gravity and every cell will be gassing at a similar rate.

NOTE:

(a) With calcium based cells very little gas is produced.

(b) Antimony based cells require an equalizer charge on initial commissioning. They also require an equalizer charge whenever it is found that there are inconsistent voltage and specific gravity values between the individual cells.

(c) Antimony based cells require more frequent equalizing charge than the calcium based.

(d) Overcharging reduces the battery life.

Calcium based cells require an equalizing charge on initial commissioning. However, provided the battery voltage is not allowed to fall below the recommended value during service, the individual cell voltages and specific gravities should not vary.

Consequently calcium based cells should not require "in-service" equalizing charges.

An equalizing charge should be stopped if any of the following are **exceeded:**

Condition	Lead Antimony	Lead Calcium
(a) the voltage per cell exceeds	2.33 V	2.41 V
(b) the specific gravity of any cell exceeds	1.240	1.275
(c) the temperature of any cell exceeds	43°C	43°C

CAUTION: Batteries must not be left on equalizing charge. Failure to observe this precaution will seriously reduce the life of the battery.

8.3 Discharging of Batteries

If batteries are discharged at too high a rate, damage will occur to the plates and the batteries life will be shortened. In addition, a battery if discharged at an excessive rate will not give its full Ampere-hour rating. Batteries are rated to be discharged over an 8 hour period. For example, a 512 Ah battery will give out 512 A ÷ 8h = 64 A for 8 hours. If the battery is discharged at 512 A, it will not be able to give this current out for 1 hour. It is therefore important, that during discharging, the battery's voltage and specific gravity are carefully and frequently monitored. Failure to do this may result in the battery becoming discharged sooner than anticipated.

8.4 Capacity Test

Periodically, typically every two years, to guarantee the Ampere-hour rating of a battery, the battery or representative cells in a battery are discharged at their current rating over an eight hour period. This discharge test is called a **capacity test.** The battery is then re-charged. The battery is not available for use while being capacity tested or re-charged.

9.0 NICKEL-CADMIUM BATTERIES

Nickel-Cadmium batteries have been used in Nuclear Generating Stations and at the heavy water plants. They are being replaced by lead acid batteries because it has been found that it is impossible to reliably check the state of the charge in cells. With lead acid cells, the specific gravity and voltage vary with state of charge. However, an examination of Figure 5 shows that the voltage in a nickel-cadmium cell does not change appreciably with the state of charge. Also, the specific gravity of the electrolyte does not vary significantly with the state of the charge. Routine tests of terminal voltage and specific gravity do not directly indicate whether the battery is charged or otherwise. Consequently, cells that are thought to have a full charge may have almost no charge. Clearly, this can lead to a serious situation when the battery is called on to supply a critical load.

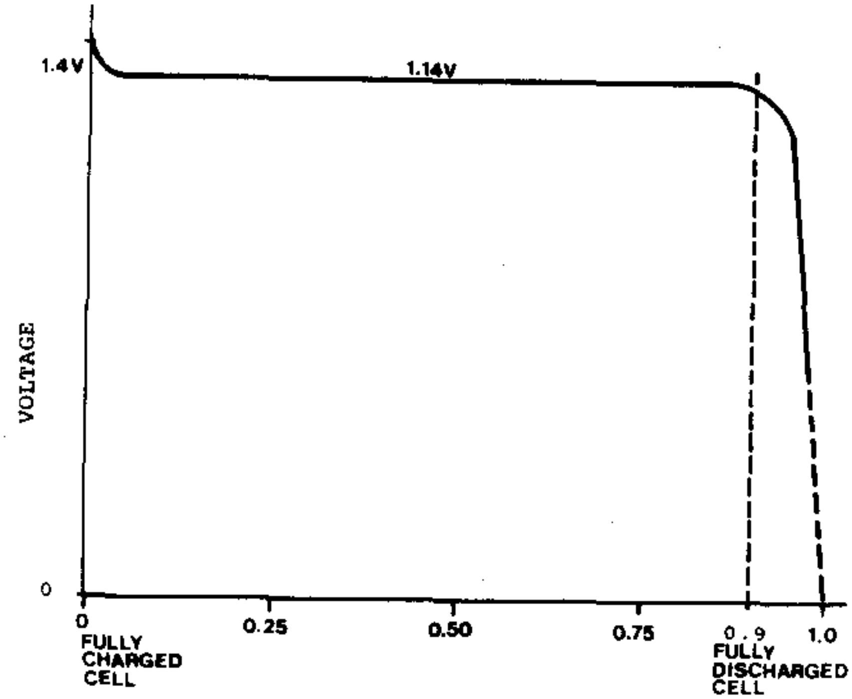

Figure 5: Curves of Terminal Voltage and Specific Gravity for a Nickel-Cadmium Cell.

10.0 BATTERY CHARGERS

A battery charger is provided for three purposes. These are to:

(a) ensure the battery is "floated" at its correct voltage,

(b) re-charge the battery following a discharge,

(c) "equalize" charge the battery.

10.1 Trickle Type Charger

A station battery could be charged using a manually regulated trickle charger of the type shown in Figure 6. The transformer reduces the voltage to the desired value, the rectifier converts the transformer ac output to dc and the variable resistor, when manually operated, controls the rate of charge.

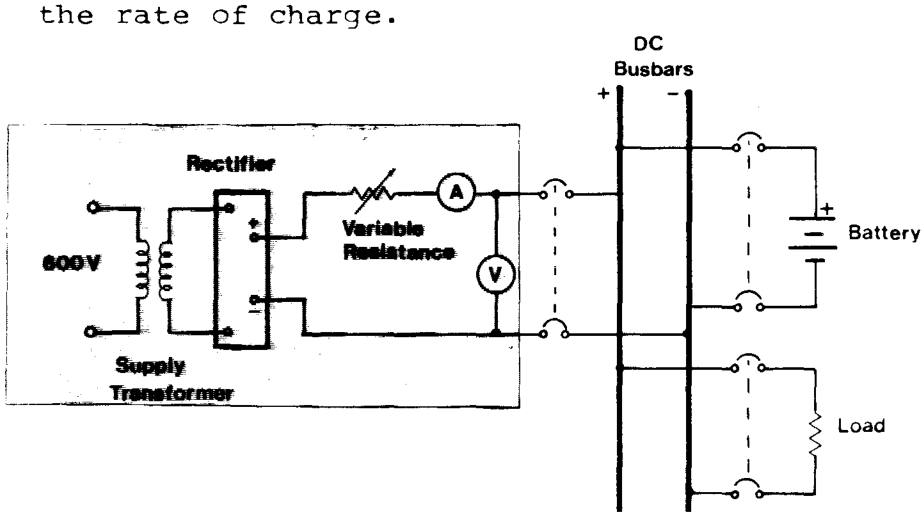

Figure 6: Diagram Showing a Trickle Charger Supplying a dc Bus Which in Turn Supplies a Load and "Floats" a Battery.

A trickle charger, unless continually supervised, will have the following disadvantages;

The battery could be overcharged if:

(a) the supply voltage rises,
(b) the load current falls,

The battery could be undercharged if:

(c) the supply voltage falls,
(d) the load current rises.

10.2 Constant Voltage Charger

To overcome the problems associated with a trickle charger, constant voltage chargers have been developed. Figure 7 shows a block diagram for a constant voltage charger.

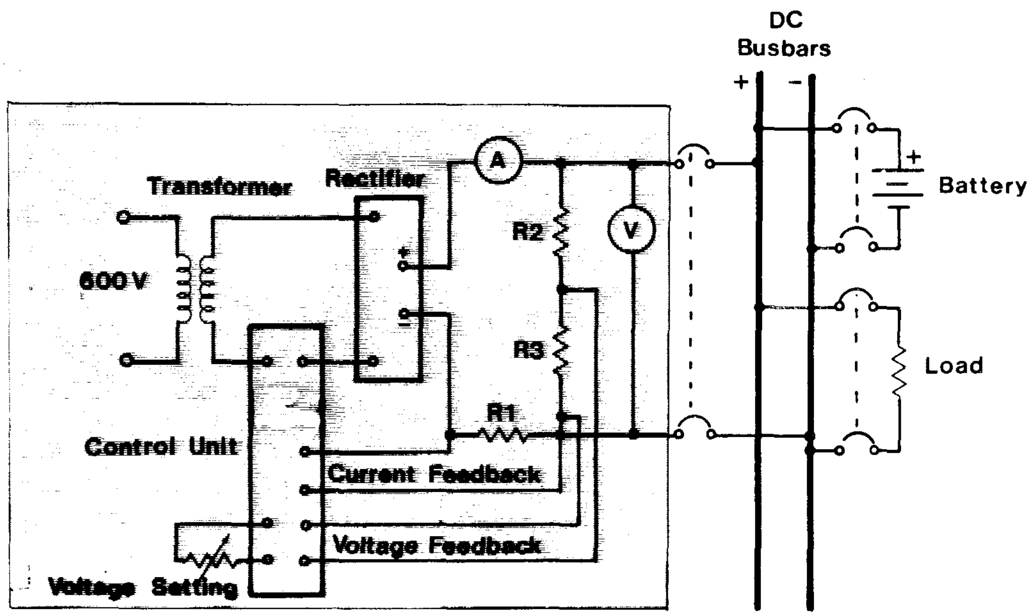

Figure 7: Block Diagram Showing the Basic Circuit of a Constant Voltage Charger.

With this type of charger, the Class III 600 V supply voltage is reduced by the transformer. The ac output from the transformer is controlled or varied by the control unit, rectified and supplied to the dc busbars.

The control unit has the following three features:

(a) A Voltage Setting

This voltage setting is manually adjusted to "instruct" the control unit make the charger give the correct voltage output.

(b) A Voltage Feedback

Resistors R_1 and R_2 act as a voltage divider and feed back a voltage, which is in proportion to the dc output voltage, into the control unit. If the dc output voltage (same as battery voltage) falls, there will be a difference between the instructed voltage and the output voltage. The control unit will sense this difference, and will increase the charger output. Conversely, if the dc output voltage **rises**, the control unit will reduce charger output.

(c) A Current Feedback

To guard against the charger being overloaded, a current feedback is provided. When current flows through R_3, a voltage is produced across R_3. This voltage is applied to the control unit and if it exceeds a predetermined value, the control unit will reduce the charger output.

This type of charger will ensure that the battery is kept full charged. It will also:

(i) Automatically adjust to all varying conditions of load.

(ii) Quickly charge a discharged battery.

(iii) Ensure the battery is kept at constant voltage so maximum life results.

(iv) Prevent the charger giving an excess current output.

For an equalizing charge, the charger has to produce a voltage which is greater than normal. When an equalizing charge is required, the voltage setting has to be manually increased. When the equalizing charge is complete, the setting is manually returned to the original position.

ASSIGNMENT

1. State the purposes of:

   (a) batteries, (3 purposes) (Section 2.0)
   (b) chargers. (3 purposes) (Section 10)

2. State the purpose of the

   (a) battery:

   (i) plates, (Section 4)
   (ii) electrolyte, (Section 4)
   (iii) pilot cell. (Section 8.2)

   (b) charger:

   (i) transformer,
   (ii) rectifier. (Section 10.1)

3. State for antimony and calcium based batteries, the conditions which show that:

   (a) the battery requires a charge, (2 conditions)
   (b) the charge is complete, (2 conditions) (Section 8.1)
   (c) the battery requires an equalizing charge, (2 conditions)
   (d) the equalizing charge is complete. (3 conditions) (Section 8.2)

4. State the three precautions that must be observed when equalize charging a battery. (Section 8.2)

5. State the four problems which can occur when a battery is charged using a trickle charger. (Section 10.1)

6. (a) Describe, using a labelled block diagram, the features and basic operation of constant voltage charger.

   (b) Explain what is meant by:

   (i) voltage setting, (Section 10.2)
   (ii) voltage feedback,
   (iii) current feedback.

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