17
Uninterruptible Power Supplies

17.1 AC UNINTERRUPTIBLE POWER SUPPLIES

17.1.1 The Inverter

Static inverters are used to convert DC voltage into AC voltage. The simplest forms of inverters produce an output waveform that is rectangular, as a result of the simple switching process described in sub-section 15.4.1. A rectangular waveform can be used to feed some types of AC equipment e.g. incandescent lamps, domestic equipment such as kitchen mixers and kettles. Equipment that contains electronic devices may not function properly if their supply waveform is non-sinusoidal. Their timing circuits and pulse generating systems may be disturbed by the shape of the waveform or its derivative.

Harmonics in the voltage waveform may create harmonic currents in the equipment that could give rise to excessive heat dissipation and ultimately damage may be caused.

All but the smaller ratings of inverters used in the oil industry require a sinusoidal output waveform. The quality of the waveform is typically defined as, being that no greater than 5% total harmonic distortion should be present. In order to achieve a sinusoidal output it is necessary to include a filter in the output circuit. The output of the inverter usually has a double wound transformer so that the required line voltage is obtained. The filter is placed on the load side of the transformer, its leakage reactance of the transformer contributes to the filtering process.

Inverters are fed from a battery bank that has sufficient cells to optimise the output voltage of the inverter and the performance of the rectifier or charger. The inverter is shown in Figure 17.1, which provides an uninterruptible supply (UPS) that also has an off-load bypass supply.

Some of the equipment in a plant requires a source of power that is extremely reliable and does not become interrupted during an emergency. For example if all the main generators on a production platform trip for some emergency reason then it is necessary to maintain supplies to vital services such as communications, public address, emergency lighting, navigational panels, fire and gas systems, see sub-section 1.2. Many of these loads can tolerate a short break and can be supplied by the emergency diesel generator once it is ready for service. Some loads cannot tolerate an interruption at all e.g. data processing systems, instrument panels, safety shut-down systems.

Inverters can be arranged to operate in various ways to provide an uninterruptible supply.

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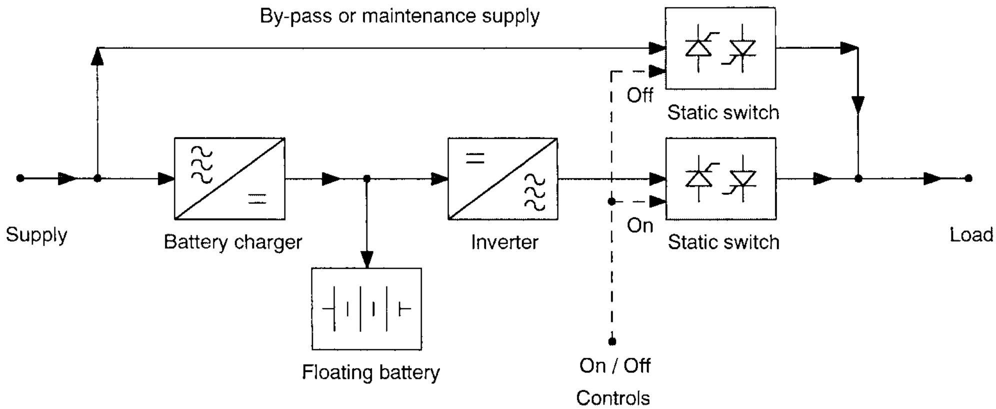

Figure 17.1 Single UPS with a bypass supply and static switches.

17.1.2 Coordination of the Sub-circuit Rated Current with the Inverter Rated Current

The output current of an inverter must not be allowed to exceed the maximum rated current of the inversion power thyristors or transistors for more than a few fractions of a second, otherwise permanent damage will be made. Consequently the inverter bridge is provided with a current limiting circuit that detects the output line total current and modifies the firing delay angle so that the bridge then functions as a constant current source. Upon detection the inverter will raise a suitable alarm and shut down. When the bridge operates in its current limiting mode the output voltage will fall to a value determined by the downstream impedance.

This situation raises an important problem with overcurrent protection. From the above explanation of current limiting it is clear that a circuit breaker or a fuse placed in the inverter output circuit lines will serve no useful protection purpose. At best the circuit breaker could be used as a switch. In practice an isolating switch is preferred especially where dual inverters feed a common load or distribution board.

The maximum rating of any one of the loads must be limited by the rapid tripping or fusing time of the device that protects the circuit. Fuses function better than moulded case circuit breakers in these situations because they are not limited by a definite minimum time constraint. To ensure that the protective device functions rapidly the rated current of this device must be limited to about 30% of the rated current of the inverter upstream. Hence the ratio of load kVA to inverter kVA of each load sub-circuit will be a maximum of about 25%.

Any fuses or moulded case circuit breakers downstream of the above mentioned protective devices should have complete coordination, as described in sub-section 7.7.5. The operating region of the upstream device should have a narrow region to the left of the asymptotic part of its curve. As the rating of the downstream device falls in value, its right-hand side characteristic will begin to come within a region to the left of the curve for the upstream device. When this occurs a degree of coordination will result. Ideally the current cut-off region of the downstream device should lie to the left of the upstream device asymptotic region. In calculating or estimating the necessary margin for coordination it is essential to account for the practical tolerances that accompany the 'nominal' curves of the devices involved. A margin must be added between the upper tolerance curve of the downstream device and the lower tolerance of the upstream device. If the two cascaded devices are of the same type, range of products from the same manufacturer, and similar shapes of curves then the margin of coordination can be relatively low. Often these cascaded devices are different, e.g. fuses upstream with circuit breakers downstream or vice versa, and their manufacturers are different. This will generally result in requiring a wider margin for coordination. A 'rule-of-thumb' guide can be based on the normal rated currents of these devices. For a good situation where the type of the two devices is the same, e.g. both are fuses or both are circuit breakers, the marginal factor should be no less than 2.5. For the poor situation with dissimilar devices the marginal factor may need to be at least 3.0. In the above discussion it is assumed that the protective devices do not have a definite minimum time at currents within the range of fault current being considered. This is a different situation from one in which the prospective fault currents are much greater than full-load currents, see sub-sections 7.7.5 and 7.7.6.

It should be noted that a UPS on an important plant, such as a production platform, is in a critical situation. It must function in a very reliable manner otherwise the cost of lost oil or gas production will be very high in relation to the cost of all the components in the UPS system that are unreliable. If the unreliability is due to poor coordinations of protective devices then the marginal factors described above may need to be reviewed, or better still applied in the early stages of the power system design.

Reference 1 gives a good description of the coordination of protective devices and their protected equipment, a diagrammatic procedure and a worked example consisting of miniature circuit breakers and an upstream fuse in a 415 V three-phase system. See also sub-section 13.3.2 for a brief discussion on the use of a high impedance to earth a low-voltage emergency or drilling power system.

Reference 2 discusses the difficulties that can be experienced with coordinating cascaded protective devices, plus a comprehensive description of all aspects of NiCd charger-battery-inverter systems.

17.1.3 Earth Fault Leakage Detection

Short circuits often develop from faults of a leakage nature. It is therefore advisable to provide each sub-circuit with an earth leakage current relay or alarm unit, which has a sensitivity that adequately coordinates with other devices. Indeed this is a necessary requirement for sub-circuits that feed power to hazardous area equipment. The use of these earth leakage current relays and detectors will greatly increase the confidence that can be placed on the overall performance of the system of protective devices in the UPS.

17.2 DC UNINTERRUPTIBLE POWER SUPPLIES

A DC uninterruptible power supply is basically a battery bank and a charger. However, it differs from a simple battery and charger system that may be associated with starting diesel engines, or similar rugged functions, because the output voltage must be maintained within a close tolerance of the nominal DC voltage.

DC uninterruptible power supplies are used for:

- Closing and tripping of circuit breakers and contactors in switchboards.
- Switchboard indicating lamps.

- Radio communication equipment.
- Emergency generator control panels.
- Start-up and shut-down lubricating oil pumps and auxiliary systems for gas turbines, large pumps and compressors.

When specifying the battery and charger system the following points should be considered.

- Rated voltage and current.
- Rated ampere-hour capacity.
- Rate of discharge
- Type of cell i.e. lead-acid or nickel-cadmium
- Ventilated batteries. Some types of cells can be non-venting but this greatly influences the charging process.
- Type of charger e.g. rectifier or thyristor.
- Boost, float and trickle charging requirements.
- Duty and standby units, and their interlocking and control philosophy.
- Volt-drop considerations in the DC outgoing cables.
- Overload and short-circuit protection.
- Tolerance on the DC output voltage during all load and charging conditions.
- Ambient temperature and appropriate derating factors for the cells and the charger.

17.2.1 UPS Battery Chargers

Battery charger technology for AC and DC UPSs can be simple as in the case of a domestic car battery charger, or complex as in instrumentation or fire and gas battery chargers. Complex battery chargers are designed to have:-

- Predetermined current and voltage versus time charging characteristics.
- Electronic protection against overloads and short circuits.
- Minimum supervision and maintenance.
- Occasionally a form of automatic duty-standby change over facility is required.

Modern chargers use fast acting and accurate electronic devices to control the desired output characteristics. The rectifying device can be diodes or thyristors.

The rectifying device is usually in the form of a single phase for units up to about 25 kVA, or a three-phase bridge-connected device for larger units. The rectifying device is fed by a single-phase or three-phase transformer. The output from the rectifier is passed through a current detection circuit (a resistance shunt or special magnetic device) and a smoothing reactor (or choke). Signals are taken from the current detector and from the output terminals, are fed back to a control circuit which produces the desired current and voltage characteristics. The control circuit also incorporates overcurrent and overvoltage protection so that the battery and its load are not damaged during abnormal conditions. Some loads cannot tolerate overvoltages, not even for a short time.

Battery chargers have an energy conversion efficiency of about 85% and a typical power factor of 0.75 to 0.85 lagging.

17.2.1.1 Charging rates

The basic method of charging batteries depends upon the type of cell i.e. lead-acid (Pb) or nickel-cadmium (NiCd). The basic method for Pb cells is 'constant voltage' where the current varies as the state of charge changes. Conversely the method for NiCd cells is 'constant current' where the cell voltage varies as the state of charge changes.

When charging Pb cells from a constant voltage source the charging current starts high and slowly decreases to a constant value when the cells become fully charged. The constancy of the current is an approximate indication that the cells are fully charged.

However, this is not the case with NiCd cells since constant current charging is preferred. The best indication with NiCd cells is the specific gravity of the electrolyte. The specific gravity should ideally be checked before and after charging, but this is not practical on a routine basis.

If batteries are kept in good condition then it is possible to predetermine a charging pattern to suit the particular battery. This is the basis upon which battery charger manufacturers are able to design their equipment. Manufacturers will provide charging and discharging diagrams for their batteries and chargers, see Figure 17.2, which shows the typical requirements for Pb cells.

It is possible to overcharge batteries and this is wasteful on electricity, causes gassing and can cause internal damage if the current is too high.

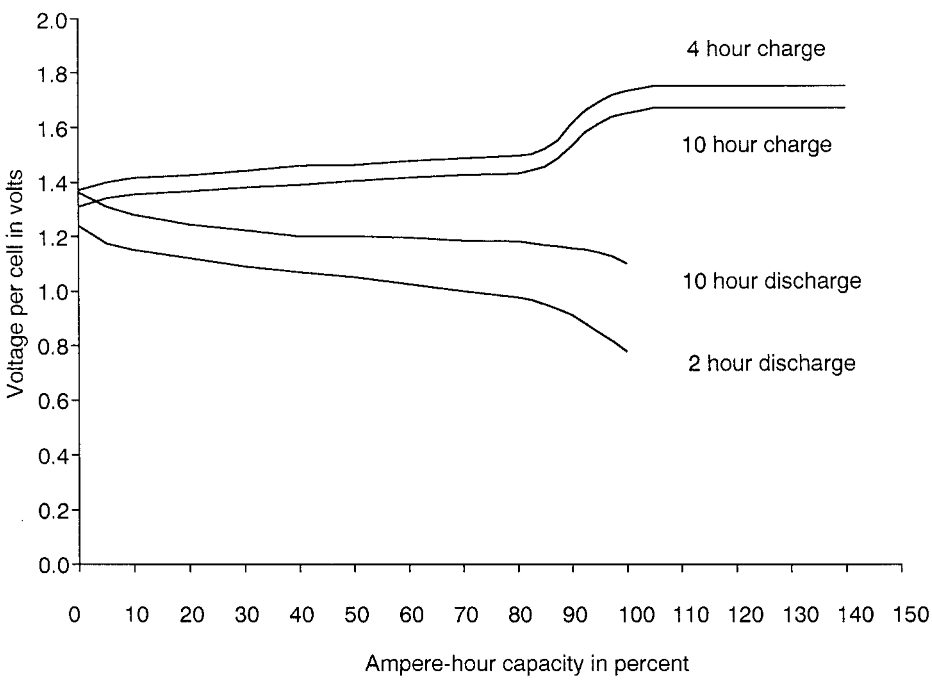

Figure 17.2 Charging and discharging of a lead-acid battery.

A ‘rule-of-thumb’ guide to the appropriate slow charging current is to divide the ampere-hour (AH) capacity of the battery (at a 10 hour rate) by about 7, e.g. a 100 AH battery would require a charging current of about 15 amps for 10 hours.

Modern chargers are usually designed to charge a battery in one or more of the following ways:-

- Float charge – for Pb and NiCd cells.
- Boost charge – for Pb and NiCd cells.
- Trickel charge – for Pb cells only.

The transfer from one method to another may be automatically or manually achieved during the charging period.

17.2.1.2 Float charge

With this method the battery is connected to its load during charging. The charger must be designed to supply sufficient current for the battery and the load. The charger operates in an almost constant voltage manner with its voltage normally just above the battery voltage. When a sudden demand of current occurs the battery and the charger attempt to share the current. However, the demand from the charger may exceed its rating and so the mode of operation then changes to constant current. The battery supplies the remaining current. The load voltage is determined by the battery during the sudden demand. The recommended float charge voltage applied to the battery during normal demand is about 2.2 to 2.25 volts per cell for Pb cells and about 1.4 and 1.45 volts per cell for NiCd cells. This will ensure full capacity is maintained in the battery without manual supervision.

Typical battery-plus-charger units can be rated up to 250 volts and 400 amps. Some oil companies prefer to restrict the DC voltage to 120 volts for safety reasons.

17.2.1.3 Boost charge

As the name implies boost charging is used to quickly restore the capacity of the battery, usually following a heavy demand. The boost current may be much larger than the rated float charging current. When boost charging is required the charger operates in the constant voltage mode but with a raised voltage. The raised voltage causes the boost current. As the battery becomes charged the boost current falls. When the current falls to a predetermined value the control circuit automatically switches the charger back into the float charge mode. An auto-manual switch is often provided to enable boost charging to be applied as required.

The elevated DC voltage may not be tolerated by the load and so care needs to be taken at the specification stage to ensure that boost charging is permissible.

17.2.1.4 Trickle charge

Trickle charging is used only for Pb cells. The current used in trickle charging is very much less than the rated battery current. The method is used for storage batteries which supply little or no current as a normal condition. They therefore remain charged for long periods and a small trickle of current is sufficient to maintain the charge.

However, batteries are best kept 'working' otherwise chemical degrading occurs internally and the battery loses performance. Batteries in these conditions should be heavily discharged periodically and immediately charged up quickly with a boost charge, if permissible, followed by a float type charge. When fully charged the mode is changed back to trickle charging.

NiCd cells should not be trickle charged, and they should be given a heavy discharge-charge cycle occasionally to ensure that their internal condition remains in good order.

NiCd cells tend to require less attention and maintenance than Pb cells.

17.2.2 Batteries

Batteries are used to store DC energy which is later used to supply a block of energy to a load, often in the form of a high current for a short time e.g. rewinding mechanism springs in switchgear, emergency lighting, emergency instrumentation power for control panels and control devices, starter motors on engines and gas turbines.

Batteries used for heavy current industrial applications are invariable of two kinds:-

- Lead-acid (Pb).
- Nickel-cadmium (NiCd).

A battery consists of a number of cells connected in series. The series connection is necessary to create sufficient load voltage. Each cell has a low voltage which is peculiar to the type of cell and independent of the current and rating of the cell. The cell voltages are shown in Table 17.1.

The maximum cell voltages during charging should not exceed 2.7 volts per cell for Pb cells and 1.85 volts per cell for NiCd cells.

Suppose a nominal voltage of 110 DC is required then at least 54 Pb cells or 89 NiCd cells would be required.

The size of a battery is defined as its ampere-hour capacity, since capacity is related to charge (Q) which equals current (I) $\times$ time (T). Hence a battery can supply a large current for a short time, or a small current for a large time.

Therefore the engineer needs to determine the nature of the load current as a function of time over a typical operating period. For example a switchgear battery may be needed to supply instrument lamps on a continuous basis and spring charging current on an occasional basis.

Table 17.1. Cell voltages

Cell type	Open circuit voltage fully charged (volts)	Load voltage during discharge (volts)	Minimum recommended discharged voltage (volts)
Pb	2.05	2.0	1.85
NiCd	1.28	1.2	1.0

If there is a total failure from the main supply then it will usually be necessary to maintain the continuous current for 4 hours so that the state of the plant will be known during the failure. During this time it would be expected that the main supply would be restored. Hence the 4 hours can be used as the 'operating cycle' of the battery in the event that the charger is unable to supply current.

Batteries may be installed in several ways, e.g. integral with the charger, in a separate cubicle or on open racks. The choice usually depends upon the physical size of the complete battery. Large batteries are more suited to an open rack installation.

17.2.2.1 Worked example

Consider the following situation as an example.

A switchboard consists of 20 circuit breakers. Each circuit breaker has, two indicator lamps each taking 1 amp continuously, a tripping solenoid taking 5 amps for one second, and a spring charging motor for reclosing which takes 3 amps for 30 seconds. The battery needs to supply current for 4 hours when a mains failure occurs. The ampere-hour (AH) duty is:-

- Lamps $20 \times 2 \times 1 \times 4 = 160$ AH
- Tripping $\dfrac{20 \times 5 \times 1}{3600} = 0.03$ AH
- Spring charging $\dfrac{20 \times 3 \times 30}{3600} = 0.5$ AH
- Contingency typically 15% = 24.08 AH
- Total capacity = 184.61 AH rounded up to 185 AH

The contingency allows for the battery being in a partial state of charge before the loss of supply. The rated AH capacity and voltage are now known. Reference 3 gives other examples plus a general description of battery charging principles.

In recent years there has been a tendency to prefer Pb cells instead of NiCd cells. This has been due to the development of what has become known as 'maintenance free' or 'sealed type' lead-acid batteries. The basic concept is one of retaining the gases evolved during the charging process and to allow the oxygen to recombine as float charging takes place, see Reference 4. If the operating and ambient conditions are not subject to excessive variation then the concept is satisfactory in practice and the life expectancy of the battery can be as much as 10 years.

If too much gas is evolved and is released through a special safety valve than the life expectancy will be reduced. The amount of gas evolved is a function of the float charging current level and the ambient temperature. The temperature of the electrolyte will be a function of the ambient temperature of the air surrounding the battery. Therefore a high float charging current and a high ambient temperature will cause the life expectancy to fall. If the ambient temperature has an average value of 30°C then the life expectancy will be halved, and at 40°C reduced to a quarter, i.e. 2 to 3 years instead of 10.

In practice it is therefore essential to ensure that the temperature within the battery room or cabinet remains reasonably constant and as close to 25°C as possible, the lower the temperature the better will be the result. At the same time the float charging current should be controlled in an accurate manner, and boost charging should not be available to the battery.

The international standards IEC60623, 60896 and 60993 are useful references for vented lead-acid and nickel-cadmium cells.

17.3 REDUNDANCY CONFIGURATIONS

It is common practice to have two inverters available to supply a common distribution board or switchboard. How they are configured and controlled depends upon the performance required when one unit fails. If a short duration interruption can be tolerated then a simple electromagnetic changeover switch can be used to switch the load over to a live standby unit. This is called a 'standby redundant' UPS system.

A better method, also called standby redundant, is to incorporate a static switch in each of the inverter output circuits. Static switches can function rapidly, with an almost imperceptible disturbance at the load terminals. One static switch is kept 'open' whilst the other is 'closed'.

A more reliable method is called a 'parallel redundant' UPS system, but it requires a more sophisticated control system. Both UPS units are energised to share the common load equally. When one unit fails it is switched out of service and the second unit takes over the full load. Figure 17.3 shows the system which also has an off-load bypass supply switched in service by a static switch. This method can be expanded to incorporate three or more units in parallel, although this is seldom found in oil industry practice. It is a practice used in the computer-based industries such as banking and financial investment. It is a method that lends itself to piecemeal expansion.

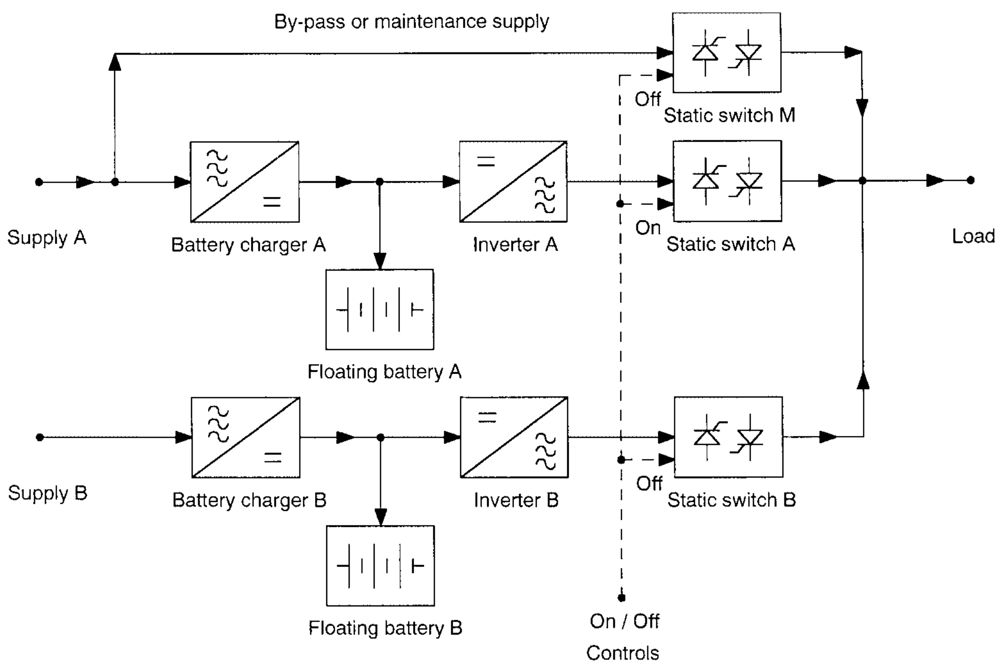

Figure 17.3 Dual redundant UPS with a bypass supply and static switches.

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