Overview of Uninteruptive Power Systems (UPS)

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Course Content

An UPS system is an alternate or backup source of standby power with the electric utility company being the primary source. The UPS provides protection of load against line frequency variations, elimination of power line noise and voltage transients, voltage regulation, and uninterruptible power for critical loads during failures of normal utility source. An UPS may be needed for a variety of purposes. The main applications include

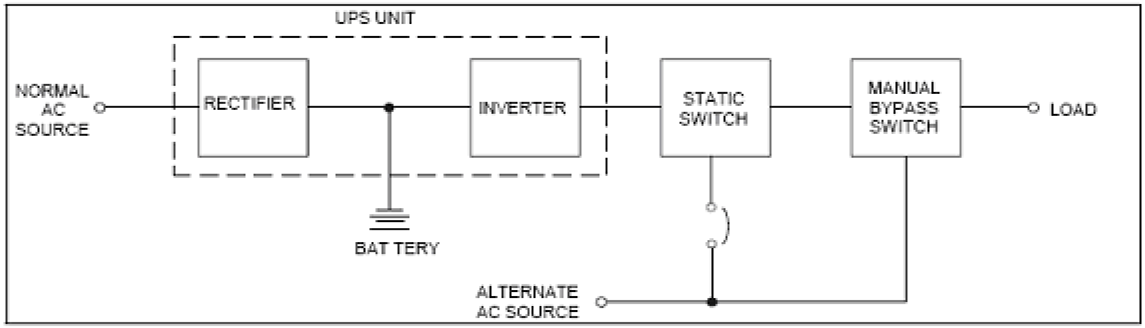
1) **Computer systems:** Computers and peripherals such as printer, monitor, speaker and modem, etc.
2) **Office:** Communication systems, computer systems, machines, OA and electrical equipments, etc.
3) **Industrial:** Communication systems, computer systems, machines, instruments-equipments, measuring instruments and electrical equipments, etc.
4) **Medical:** Critical life support applications such as operation theaters in hospitals, intensive care units, emergency medical equipments and surgical equipments, etc.
5) **Telecommunication:** Communication equipments, microwave networks, traffic control systems and satellite earth stations, police communication networks, aircraft landing systems, repeater substations, telecommunication control room, etc.
6) **Process control:** Data processing and report systems of banking and stock exchange, oil & gas control rooms, power stations etc.
7) **Home:** electrical equipments such as TV, stereo, radio and fan, etc., and computers and peripherals
8) **Miscellaneous:** Emergency lighting for evacuation, perimeter lighting for security, orderly shut down of manufacturing or computer operations

The UPS can be broadly classified into two categories the rotary type and the static type.

STATIC UPS

A static UPS is a solid-state system relying solely on battery power as an emergency source. The main building blocks of static UPS systems are a rectifier, inverter, and an energy storage device i.e., one or more batteries. The inverter in the static UPS also includes components for power conditioning.

Modern static UPS systems are constructed with ratings ranging from about 220 VA to over 1 MVA. Figure below shows a simple static UPS schematic.



Simple Version of a Static UPS

OPERATION

The static uninterruptible power supply (SUPS) basically consists of four major blocks. They are the battery rectifier/charger, battery bank, inverter and the transfer switch.

Normal Mode Operation

1) The rectifier/charger receives the normal alternating current (AC) power supply, provides direct current (DC) power to the inverter, and charges the battery.

2) The inverter converts the DC power to AC power to supply the intended loads.

Upset Mode Conditions

1) *Loss of normal power*- Upon loss of AC power supply or upon failure of the rectifier or when the AC supply voltage sags below acceptable limits, the battery maintains the DC supply to the inverter. This mode of operation continues until the system is shut down, when the battery reaches the discharged state before the charger output is restored.

2) *Restoration of power* - Upon restoration of the AC supply, the rectifier output voltage is set at the equalizing voltage to recharge the battery. The charger will also supply the inverter while recharging the battery. At the end of the battery recharging time, the battery charger returns to the floating mode and the system returns to normal operation.

Bypass Mode

1) In the event of the failure of the inverter, the static switch automatically transfers the load to an alternate AC source. The bypass switch is also useful in clearing load faults downstream of the UPS.

2) The static UPS systems may have three bypass switching arrangements: 1) the UPS static switch; 2) the UPS static switch circuit breaker and 3) the maintenance circuit breaker.

COMMON STATIC UPS SYSTEM CONFIGURATIONS

The building blocks of a static UPS system are rectifier/charger, inverter, battery, and static switch. These building blocks can be assembled in many configurations as required to meet reliability and/or economic considerations. However, some specific configurations have been in common use and are standardized in Institute of Electrical and Electronic Engineers (IEEE) 446. The most common of these configurations are

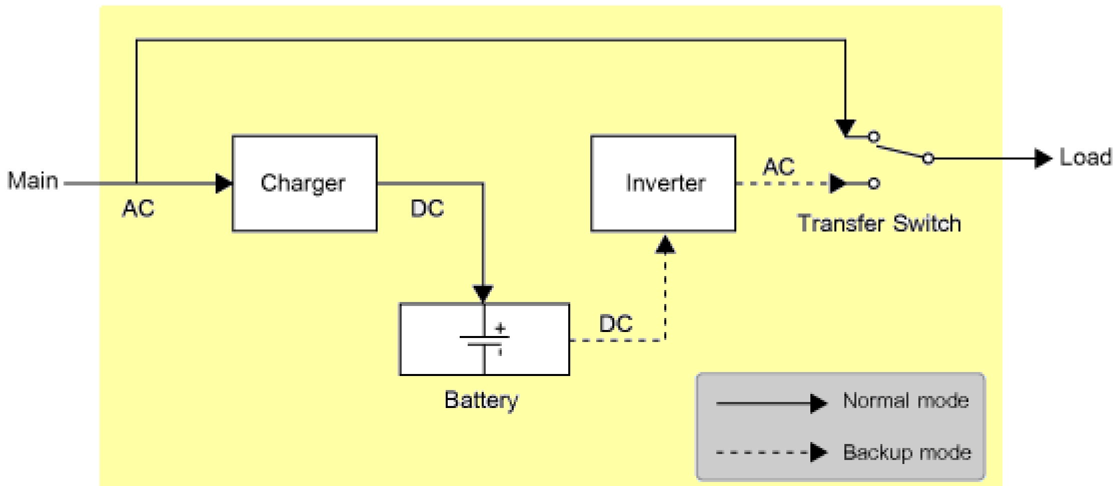
1) Offline UPS or standby power systems

2) Online Protection UPS or line interactive UPS

3) Double conversion UPS (on-line)

1) Offline UPS or **Standby UPS**

In this type of supply, power is usually derived directly from the power line, until power fails. After power failure, a battery powered inverter turns on to continue supplying power. Batteries are charged, as necessary, when line power is available. This type of supply is sometimes called an "offline" UPS.



In the normal mode, the load is directly supplied with the utility power supply at the same time the charger charges the battery. In the event of a blackout, the battery will supply power to the inverter that will supply AC power to all connected loads. The transfer switch is used to switch between the utility power supply and the inverter. The time required for the inverter to come on line is termed “switchover time”.

The offline UPS or standby UPS is only designed to protect the loads from a blackout, it cannot protect from the variations in voltage and electrical noise, therefore, its cost is lower than the other types. Moreover, it is unsuitable to use in any places where close to generated power sources such as dams, power stations and substations, etc.

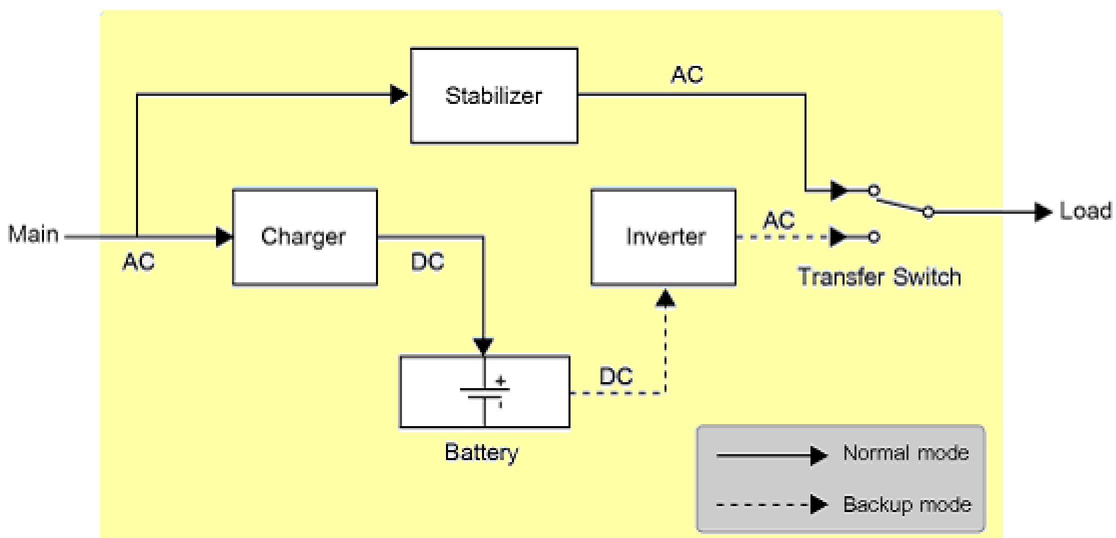
Essential characteristics are summarized below:

- The standby UPS does not regulate incoming power and is not recommended for networking systems. Only those loads which can tolerate power line transients and harmonics can be used under this configuration.

- Protect only a blackout and does no power conditioning during normal operation
- Load sees brief interruption when switching to battery backup
- Square wave or quasi sine wave output under backup power
- Typically small (up to 10 kVA), single phase
- The rectifier has to supply only the no load current to the inverter and it should maintain the battery bank in a floating condition.
- One major limitation in this configuration is that failure of the inverter leads to the loss of power to the supplied loads. Another limitation is that due to the limited overload capability of the inverter elements, it is not suitable for supplying loads with high inrush current requirements.

2) Online Protection UPS or **Line Interactive UPS**

The online protection UPS or line interactive UPS is similar to the Offline UPS but it includes the stabilizer. In the normal mode, the load is directly supplied with the utility power supply through the stabilizer and at the same time charges the battery. The stabilizer functions to regulate the AC voltage to constant range and protects the supply from brownout, surge and spikes. In event of a blackout, the battery will supply DC power to the inverter, which functions to supply AC power to all connected loads. The transfer switch is used to switch between the commercial line and the inverter.



Essential characteristics are summarized below:

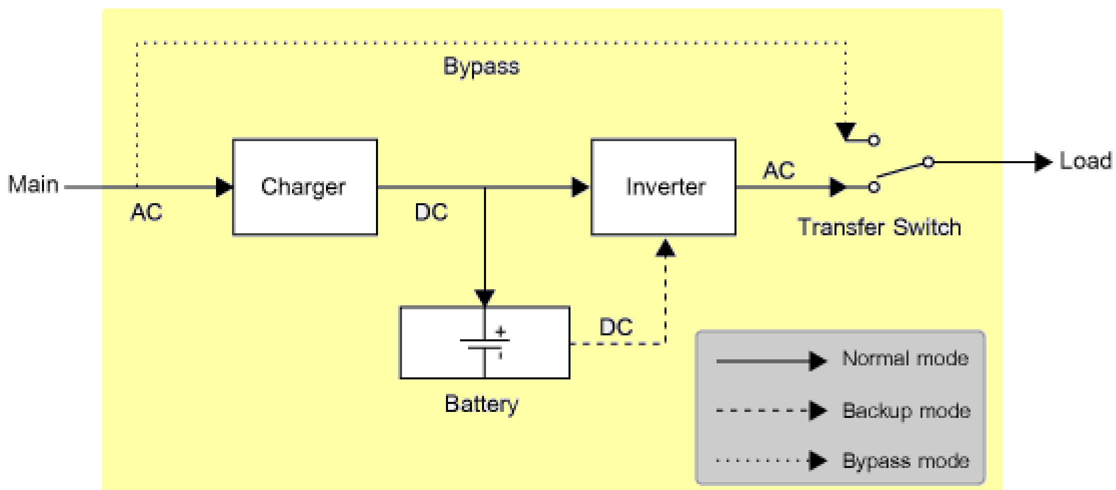
- Suitable to use in some places where there are many variations in voltage.
- Power passed to the load through magnetic components (inductors, transformers)
- Inverter interacts with magnetic components to boost or buck input voltage

- Incompatible with the sensitive electrical equipments such as medical equipments and industrial instruments, etc.
- Provides some power conditioning but frequency variations are passed to load
- Typically 100 kVA or less, 1- or 3-phase

3) Double conversion (On-line)

In a double conversion online UPS, the load always receives the power from the inverter. The charger and inverter will operate all the time. Whatever its power conditions, the UPS always supply clean power to all connected loads until the storage batteries are flat or when the inverter malfunction, it will supply power from the utility power supply to all connected loads.

An online UPS works always from a floating battery and the battery is parallely being charged when mains is present so that battery doesn’t get discharged at all. When the main AC fails, the battery bank supplies the current to the inverter and hence the inverter continues to feed the load. Only when the inverter or, the rectifier develops some problem, the load is switched to the commercial line.



On-line UPS products are ideally suited to networks running mission-critical applications, which make it the most widely used configuration. Essential characteristics are summarized below:

- The input voltage is directly supplied via the UPS and there is zero switchover time.
- Online UPS seamlessly draws power from DC storage when input voltage is lost
- Some on-line UPS can compensate for under-voltage and over-voltage without using the battery, saving battery time for use only in complete blackouts.
- Single-phase or three-phase, ratings can exceed 1000 kVA, higher if paralleled

MAJOR COMPONENTS CHARACTERISTICS

After having seen the different configurations, the various major assemblies of the UPS can now be discussed.

<u>Rectifier</u>

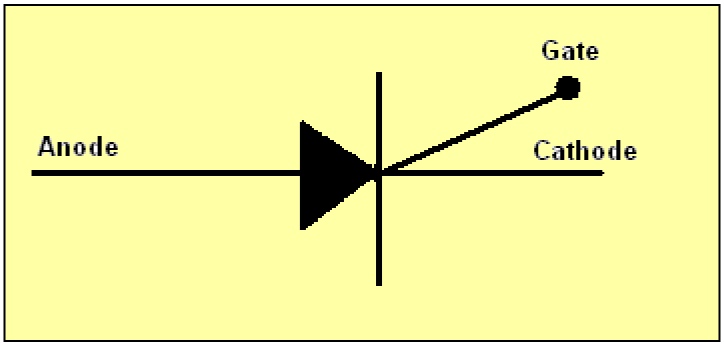
Rectifier is a device for the conversion of AC power to DC power.

- ***Controlled rectifiers-*** In a controlled rectifier, the output DC voltage can be continuously maintained at any desired level.
- ***Un-controlled rectifiers-*** In an uncontrolled rectifier the output DC voltage (at no load) is a fixed ratio of the input AC voltage.

Rectification is accomplished by using power semiconductor devices such as SCRs or IGBTs. These solid-state devices control the direction of power flow and switch on and off very rapidly allowing for the conversion of power from AC to DC and DC to AC.

1) A power semiconductor is an electronic device consisting of two layers of silicon wafer with different impurities forming a junction made by diffusion. The joining of these two wafers provides control of the current flow.
2) The power semiconductor permits the current to flow in one direction from the anode to the cathode, <u>whenever the anode voltage is positive relative to the cathode</u>. When the anode voltage is negative relative to the cathode, the power diode blocks the flow of current from the cathode to the anode.
3) The power semiconductors may be either Silicon Controlled Rectifier (SCR) or transistors. The types of transistors are bipolar transistors, field effect transistors (FET), and insulated gate bipolar transistors (IGBT). The IGBTs are significantly more efficient and easier to control than the other power semiconductors. The use of IGBTs has allowed for static UPS as large as 750 kVA without paralleling units.

Silicon Controlled Rectifier (SCR) - SCR is a solid state device that allows for forward flow of current through the device similar to a diode. *The SCR differs from a diode in that the SCR will not conduct until a current pulse is received at the gate.* Once the SCR is conducting, it will only turn off with the current falling to zero or through a reverse current being applied.



SILICON CONTROLLED RECTIFIER (SCR) SYMBOL

The SCR operates in two modes:

1) ON-state (forward-conduction, low-impedance) - When a gate current is applied, forward conduction from the Anode to the Cathode occurs and the SCR acts as a conducting diode.

2) OFF-state (open-circuit; almost infinite impedance) - When the magnitude of the forward current falls below a holding-current threshold and no gate current is applied, forward conduction stops and the SCR acts as an open circuit.

While turning on the SCR is very efficient, the SCRs require a commutation circuit to turn it off. *The turn-off time is slow in comparison to the transistors which are non latching devices.* The other drawbacks to the commutation circuit are that it adds more equipment to the circuit, adds audible noise to the unit, and consumes power.

Bipolar transistors- Bipolar transistors permit current to flow through the circuit when current is applied to the base. The flow of the power through the device is proportional to the current applied to the base. Unlike SCRs, transistors are non-latching. Upon removing the current from the base, the circuit will be turned off. This allows for much quicker switching time than the SCRs. However, bipolar transistors experience high saturation losses during power conduction and require drive circuits to minimize switching losses.

Field Effect Transistors (FET) - FETs are turned on and off by applying voltage to the gate. This is more efficient than applying current to the base as done with the bipolar transistors. The FETs however experience saturation losses and require drive circuits to minimize the switching losses. Moreover, the high resistance characteristics of the power conducting portion make this device inefficient and undesirable for large applications.

Insulated Gate Bipolar Transistors (*IGBT) -* The IGBT combines the desirable characteristics of the bipolar transistor and the FET. Voltage is applied to the base to turn the device on and off and the collector/emitter has low resistance. IGBTs have a greater tolerance to temperature fluctuations than the FETs. The IGBTs have the drawback of saturation losses and switching losses like all of the other transistors. These must be taken into consideration in the designing of the UPS. Overall, the IGBT is more efficient and easier to control than the other power semiconductors.

Inverter

Inverter is a device that is responsible for converting DC power to AC power. It determines the quality of the power fed to the load and generally has all protections to lake care of sudden surges in output load or the under / over - voltage conditions at the input. The two most commonly employed inverter technologies in UPS today are pulse width modulation (PWM) and constant voltage ferroresonant transformer.

Pulse Width Modulation (PWM) - In this technique, the inverter SCR pairs are switched on and off many times every half cycle to provide a train of pulses of constant amplitude and different widths. By this technique the output voltage wave shape can be made to closely approximate a sine wave.

The control of voltage and current is achieved by adjusting the pulse width as required by load changes. The effects of these load changes are sensed and fed to the control logic circuitry through feedback circuits comprised of voltage and current sensing devices, thus adding design complexity. The switching frequency of this type of inverter is between 30 KHz and 50 KHz and due to the fast switching speeds; turning off the device is crucial.

PWM Inverters are more sensitive to non-linear currents and often must be oversized for proper operation. It has a very high efficiency and its response to power line transients is quick. But due its complex design it is very costly and hence it is used only in high capacity UPS systems.

Ferroresonant transformer- The ferroresonant transformer basically consists of a square wave inverter and a tuned output transformer that is responsible for current limiting and regulation of voltage. The transformer usually has an additional small secondary compensating winding and a series low pass filter connected across part of the main secondary winding. The filter presents low impedance to the lower order harmonics and reduces their amplitude in the output to a low acceptable value. The compensating winding voltage is added to the secondary output voltage 180° out-of-phase thus maintaining the output voltage within a narrow regulation band. However, with the use of a ferroresonant transformer, *the output voltage is not continuously adjustable* as in the PWM circuitry. Ferroresonant Inverters are uniquely compatible with switching-mode power supplies and do not have to be oversized to provide proper operation. It can be easily connected in parallel to many units. The main disadvantage is the large size of the transformer and the low efficiency of about 70 to 75%. Normally this type is not used above 20 - 25 KVA rating.

The following list itemizes advantages and disadvantages of both technologies.

PWM Advantage

1) Small physical size
2) Low audible noise
3) Higher efficiency
4) Better transient recovery from a 0 - 100% step load change

5) Maintenance free batteries do not require ventilation

6) Large number of fixed alarm selection

PWM Disadvantages

1) More components (lower reliability thus increasing long-term cost)

2) Complex circuitry (frequently requires factory technician for maintenance)

3) Difficult to repair

4) Environmentally sensitive (electrical and atmospherically)

5) DC battery voltages are not compatible with station batteries in many cases

6) Input transformer is often not used (rectifies "off the line" resulting in no isolation

7) Monitoring and alarm functions are displayed one at the time

8) Limited faults clearing capability, if bypass is not available. (Typically 200-300% vs. 500%; especially important when feeding branch distribution panels)

9) Limited reliability if environmental and maintenance conditions are not met

10) Multiple circuit boards

11) Normally use sealed maintenance free batteries, which provide limited life and are not environmentally tolerant

12) Short design life (obsolete design life)

Ferroresonant Advantages

1) Simple proven design

2) Few components

3) Easy to maintain (can be done by plant electrician)

4) Rugged construction

5) Complete monitoring and alarm functions

6) Excellent fault clearing capability without bypass (500%)

7) Many spare parts commercially available

8) Environmentally tolerant

9) 125 and 250 VDC standard battery voltages

10) Reliable under all operating situations

11) Compatible with high crest factor non-linear loads

12) Design life of more than 20 years

Ferroresonant Disadvantages

1) Footprint physically larger than PWM

2) Higher acoustical noise

3) Less efficient than a PWM

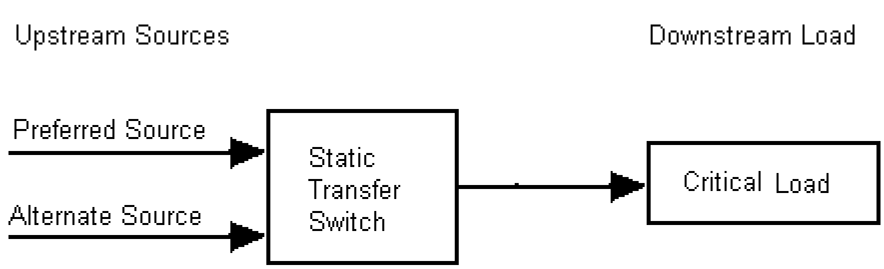
4) Higher initial expense (first cost), but long-term cost savings related to more up time and less maintenance expenses

Although each method may have some advantages over the other, the voltage control method is normally not specified when specifying UPS systems. Either type may be used provided it meets the performance requirements. For industrial applications where high reliability and ease of maintenance by plant personnel is of utmost importance, the more rugged ferroresonant approach is generally favored whereas PWM are more suitable for commercial computer rooms, datacenters and EDP environments.

Transfer Switch

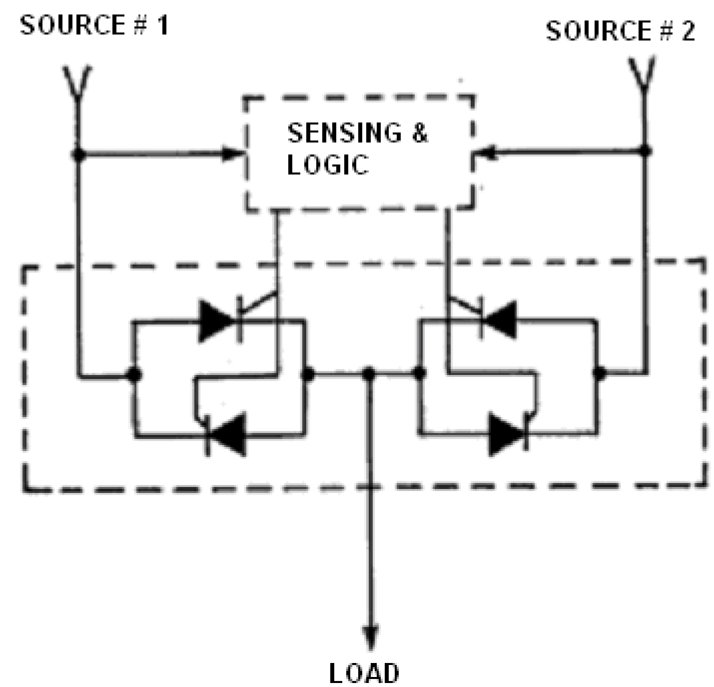
The Static Transfer Switch (STS) selects between two or more sources of power and provides the best available power to the electrical load downstream. This high speed device should be capable of switching the load from one source to another with in a few milliseconds because most of the equipments can tolerate only this minimum switching delay. It has some very complex sensing circuits to monitor the inverter output and the commercial AC line, so that the load can be properly switched to the correct source of power at all times.

STATIC TRANSFER SWITCH SYSTEM



Design and Operation

The basic ON-state and OFF-state properties of the SCR are used to form an intelligent switch which can choose between two upstream power sources and provide the best available power to the electrical load downstream. A static transfer switch consists of two pairs of SCR. *Each pair is connected in back-to back* *(anti –parallel) arrangement on preferred and an alternate side of the switch, i.e., the anode of one SCR is connected to the cathode of the other.* By this arrangement, each SCR in the pair can be made to conduct every other half cycle. One pair of SCR is connected between the load and each of the two sources. The logic circuit applies firing signals to either pair of SCR.



Single- Phase Static Transfer Switch

Operation

During normal operation, SCR associated with the preferred source are in the ON-state, while those associated with the alternate source are in the OFF-state.

Current sensing circuits constantly monitor the states of the preferred and alternate sources and feed the information to the supervisory microprocessor controller. Upon sensing the loss of the preferred source, the microprocessor control instructs the gate-driven SCR on the alternate side to turn ON. The transfer from the preferred to the alternate source is so fast (less than ¼ electrical cycles), that even the most sensitive electrical or electronic loads are unable to determine its occurrence.

Since it is entirely based on solid state technology, the static transfer switch has no mechanical moving parts and thus requires minimal maintenance. It has an AC-to-AC efficiency in excess of 99%, does not require air-conditioning, has a small footprint and requires no batteries when used as an alternative to the Uninterruptible Power Supply (UPS).

Batteries

A battery is used in a static UPS system to provide reliable emergency DC power instantaneously to the inverter when the normal power fails or degrades. Several types of batteries are used such as Lead-Antimony, Nickel -Cadmium, Gel electrolyte, Lead acid and Lead-Calcium. Lead-Antimony requires complicated charging techniques and a high level of maintenance. Nickel-Cadmium offers a high storage level but a high cost. It is extremely well suited for conditions with space limitations or where the temperature is very low. The Gel electrolyte battery is used mostly in smaller UPS systems. It is costlier than the liquid electrolyte lead acid battery, but the main advantage is that it is scaled and maintenance free.

The batteries may be of the high rate, medium rate, or low rate design.

- The high rate batteries are designed to deliver a large amount of current over a short amount of time of approximately 15 minutes. This is achieved by designing the batteries with thin plates. <u>This design is most common for UPS applications.</u>
- The medium rate batteries are designed for general use. They deliver a medium amount of current over a medium amount of time of approximately 1 to 3 hours. The design consists of medium width plates. <u>This design is most common with switchgear and control applications.</u>
- The low rate batteries are designed for delivery of power over a long amount of time of approximately 8 hours. The battery design consists of thicker plates. <u>This design is most common for applications such as emergency lighting and telecommunications.</u>

Of the many available battery types, the following two basic types are generally used in static UPS systems, namely, the Lead-acid and the Nickel-Cadmium (Ni-Cad) batteries.

Lead-Acid Batteries

Lead acid batteries have been the primary energy storage medium for a long time in industrial applications. The Lead-Acid batteries have following characteristics:

1) A lead-acid battery cell consists basically of a sponge lead negative electrode, a lead dioxide positive electrode, and a sulfuric acid solution as an electrolyte. At the end of the charging process, water electrolysis occurs producing hydrogen at the negative electrode and oxygen at the positive electrode.
2) Batteries are connected to the charger such that the two voltages oppose each other i.e. positive of battery is connected to positive of charger and negative to negative.
3) Battery current flow is the result of the difference between the battery and the charger voltages and the battery's extremely low opposing resistance. The voltage of the battery rises during charging, further opposing current flow.

4) A nominal system design may utilize minimum end voltage of 1.67 to 1.75 volts per cell and a maximum specific gravity of 1.215 at 77°F. A commonly used end or discharged voltage is 1.75 volts, however lower end voltages are also possible.

   - A higher specific gravity may result in a battery installation needing less space, but results in shorter life spans and higher cell losses and float voltages. The lower end voltages may cause overstressing battery plates, shorten the life of the battery.
   - The excess energy of higher float voltages results in loss of water, cell gassing, accelerated corrosion, and shorter cell life. To eliminate such actions, the charge is stopped slightly short of a fully-charged condition on daily or frequent discharges.

5) Lead-acid batteries are susceptible to high temperature and the life of a lead-acid battery is reduced by 50 percent for every 15°F increase in electrolyte temperature. These are well suited for industrial applications and have the long life span (20 years).

6) Since the charging cycle of lead –acid batteries produces hydrogen-oxygen mixture, the National fire protection association (NFPA) code requires the hydrogen concentration shall not exceed 1ppm in battery room. The battery room shall be exhausted @ 10 air changes per hour with twin explosion proof exhaust fans.

Valve Regulated Lead-Acid (VRLA) Batteries

1) *The VRLA batteries* are sealed with a valve allowing venting on excessive internal pressure. These cells provide a means for recombination of the internally generated oxygen and suppression of hydrogen gas evolution to reduce the need for adding water.

2) This design does not require the maintenance of checking the specific gravity and adding electrolyte as does the flooded lead-acid batteries. These batteries have a lifetime of approximately 5 to 6 years. This is substantially shorter than the 20 year lifetime of the flooded lead-acid and the 25 year lifetime Ni-Cad designs.

3) These units sometimes experience failures called “sudden death failures” where deposits form on the plates causing a short. This type of failure is difficult to detect and makes this battery less reliable than the flooded lead-acid design and the Ni-Cad design.

4) The VRLA batteries cost approximately half of the price of the flooded lead-acid batteries and one fourth of the price of the Ni-Cad batteries.

5) These units are well suited for UPS systems providing back up to computer systems because of their low maintenance costs and low emissions. For industrial applications requiring greater reliability and longer life the flooded lead-acid and Ni-Cad designs are preferred.

Nickel – Cadmium (Ni-Cad) Batteries

1) The Ni-Cad battery cell consists basically of a nickel hydroxide positive electrode, a cadmium hydroxide negative electrode, and a potassium hydroxide solution as an electrolyte.

2) The nominal voltage of a Ni-Cad cell is 1.2 volts while the open circuit voltage is 1.4 volts. The electrolyte specific gravity is approximately 1.180 at a temperature of 25°C (77°F). The usual recommended float voltage for UPS applications is 1.38 to 1.47 volts per cell depending upon the manufacturer's recommendation. Overcharge, as such, may cause no harm to the battery although there will be water loss.

3) Lower specific gravities are generally used in cells with larger electrolyte reserves. Higher specific gravities are typically used for low-temperature applications. The specific gravity will decrease slowly over the years because of evaporation and other effects, even though the surface of the electrolyte is probably covered with a protective layer of oil. Renewal will be necessary, if the specific gravity decreases to 1.130 to 1.160.

4) Ni-Cad batteries are also available in one of three designs of high, medium, or low rate power delivery. The high rate batteries are the most commonly used in the application of UPS systems.

5) These batteries are resistant to mechanical and electrical abuse. They operate well over a wide temperature range of –20°C to 50°C. Also, they can tolerate a complete discharge with little damage to the capacity of the battery.

6) Ni-Cad batteries exhibit a longer life and a more rugged construction. However, for a similar capacity rating, a Ni-Cad battery requires approximately 53 percent more cells than a lead-acid battery at the same voltage and are 50% more expensive. These however a long lifetime of 25 years.

7) The life of a Ni-Cad battery loses approximately 15 percent of its life for every 15°F increase in electrolyte temperature.

Battery Charger

A battery cannot function without a charger to provide its original and replacement energy. A well designed charger will act to charge a discharged battery by maintaining the correct balance between overcharging and undercharging so as not to damage the battery. Additionally, the charger must assure that battery discharging is limited to the point where the cells approach exhaustion or where the voltage falls below a useful level (usually about 80 percent of the batteries rated capacity). Overcharging results in increased water use and over-discharging tends to raise the temperature, which may cause permanent damage, if done frequently.

1) The battery charger provides the initial charge, replenish the local losses to maintain the battery capacity, equalize the individual (lead-acid) cells state-of-charge, and recharge the battery following discharge.

2) Safety margin is provided on the charger to take care of any overload condition at the inverter output. After an emergency condition, when the charger starts charging the battery bank a heavy current will be drawn by the battery bank. This should be taken care by the current limiting circuit of the charger.

3) The rating of the battery charger depends on the load, the inverter efficiency, the current needed to charge the battery bank etc. If the time required recharging the battery bank after a mains failure is to be short, then the size of the charger goes up.

4) In static UPS systems, the battery is continually connected to the charger and the load and the battery is float charged. During float charging the battery charger maintains a constant DC voltage that feeds enough current through the battery cells (while supplying the continuous load) to replenish local losses and to replace discharge losses taken by load pulses exceeding the charger's current rating.

5) Periodically the charger voltage is set at a level 10 percent higher than the floating voltage to restore equal state-of-charge at the individual (lead-acid) cells. This mode of charging is called “equalizing charge”. Following the battery discharge, the charger is set at this higher voltage to drive a higher charging current to recharge the battery in a reasonably short time and to restore it to the fully charged state. At the floating voltage level, the Ni-Cad cell cannot be charged over 85 percent of its full capacity. Therefore, the equalizing voltage level is required to fully recharge the cell after successive discharges.

6) Chargers must maintain a sufficiently high current throughout charging so that at least 95 percent of the complete storage capacity is replaced within an acceptable time period. This recharge time may range from 5 to 24 times the reserve period (for a 15 minute reserve period with a 10 times recharge capability the recharge period would be 1.5 hours).

7) Electromagnetic Interference (EMI) filler is generally included at the input of the battery charger/rectifier to prevent electromagnetic interference from going to the commercial line. EMI can be generated by the switching thyristors of the battery charger / rectifier. Its output is filtered by low pass filler.

Battery Ratings

Batteries are available in different voltage ratings such as 2V, 6V, 12V, etc of which 12V is the most popular of all the lot. Suppose a UPS is designed with 120V DC battery voltage, it requires at least 10 numbers of 12V batteries to work the system. The size of each of these batteries determine the backup time available after power failure. *Battery capacity is measured as AH (Ampere Hour) and will vary from say 1AH to 300AH. Generally the bigger the battery more AH it will have.*

Battery Sizing

The size of the battery bank is determined by factors such as

1) The load for which it should supply power

2) The time for which it should provide back up

3) The input voltage required by the inverter

4) The efficiency of the inverter

When sizing battery for the UPS systems ask the following questions:

1) What is the rating of the equipment/UPS say 600VA, 800VA, 10KVA......?

2) What is the battery capacity required measured in ampere hour (AH). For example 300AH

3) What is the *DC Voltage* requirement of the UPS? For example: 500VA may work on 12V, 1KVA may work on 24V, and 5KVA may work on 120V.

4) What is the *backup time* (BT) the consumer requires? For example: 3 hours.

The relationship between these variables is given by equation-

*BT in hours= DC Voltage of battery * AH of battery / VA of the equipment*

Actually this formula is with the assumption that battery is 100% efficient which may not be the case and so it will be less than what we got from formula.

Battery sizing examples:

Example#1

If the customer wants 400VA equipment and 3 hours backup time, what battery rating should be selected? Consider 400VA equipment works on 12V.

Solution:

AH of the battery = Backup time in Hrs* VA of the equipment/ DC Voltage of battery

Or AH of the battery = 3 x 400/12=100

Therefore we will select 100 AH 12V battery.

Example #2:

A customer wants to buy 5 kVA UPS suitable for approximately 4kW load with 2.5 to 3 Hrs backup. What battery rating should be selected? Consider voltage of battery to be 120V.

(a) Capacity of the equipment = 5kva = 5000VA

(b) Voltage of battery = 120V (because 5000VA UPS works on 120V battery)

(c) Backup time required = 2.5 to 3 Hrs

AH = 5000 * 2.5/120V = 12500/120 = 104 AH

AH = 5000*3/120V=15000/120 = 125 AH

Since the batteries available are 20,40,60,80,100, 120, 140AH therefore the choice would be 120AH/120V battery. This will suffice the backup time requirements of approximately 2.5 to 3 hours. Since each battery is 12V; provide 10 Nos. of 120AH batteries to make 120AH/120V system.

Example #3:

A customer has a 400VA inverter and 100AH battery. How many hours will it run to operate a single computer with 160VA rating?

BT = AH x Voltage/VA

AH of battery = 100AH, Voltage of Bat = 12V and VA connected as load = 160VA

BT = 100 * 12/160= 7 hours

Tips:

- Always converts to Hours the backup time required for example 15 Minutes = 0.25 Hrs.
- Always convert KVA to VA, 1 KVA = 1000VA
- The answer from the formula is for ideal calculations, in practice the backup will be less than the calculated value.

Discharge rate - For UPS system battery, the discharge rate should correspond to the highest inverter input power required to produce rated output at minimum input DC voltage. The minimum DC voltage required by the inverter is normally published by the manufacturer. In addition, it is recommended to include a margin of 30 percent for the required capacity to account for load growth and battery aging.

Lifetime- The end of life of battery is defined as the failure of battery to be able to deliver a certain percentage of rated capacity. The expected lifetime of batteries on UPS duty is usually stated in terms of years of service on continuous charge. Initial capacity (unless specified as 100 percent capacity) is usually in the range of 90 to 95 percent of rated capacity. This will rise to 100 percent capacity in normal service after several charge-discharge cycles. *IEEE 450 recommends that a battery shall be replaced when its actual capacity drops to 80 percent of rated capacity.*

Criteria for evaluating UPS battery

Criterion	For Reliable Performance and Longer Life
The thickness of the positive plate	Thicker is better for durability
The material used for the battery posts	Copper inserted posts operate more efficiently and cooler, and require less frequent re-torque than do lead posts
How the batteries are tested at the plant	Cells should be tested together
Capacity at which the batteries are shipped from the factory	Anything less than 100% makes it debatable whether 100% can ever be achieved
Tolerance to temperature above 77°F	The higher the better
Frequency at which a boost	Less frequent is better

charge is needed	
Frequency at which testing is required	Less often for short times is better

End of discharge voltage- Battery voltage is not constant, so if the load requires a constant power output, which most UPS applications do, the current must increase as the voltage decreases. Consequently, the battery is sized to supply a specific kW rate (usually the maximum inverter kW requirement without recharging) for a specific period of time (usually 5 to 15 minutes) to a minimum specific end voltage and, for lead-acid types, at a maximum specific gravity (measured at 77°F). *The end of discharge voltage shall be equal to or higher than the minimum DC input voltage required by the inverter to maintain rated performance.*

Temperature correction- Ratings are at 77°F (25°C). Therefore, to determine specific gravity, which is temperature sensitive, a temperature correction factor must be applied. For both lead-acid and Ni-Cad batteries, add one point (.001) to the hydrometer reading for every 3°F above 77°F and subtract one point for every 3°F below 77°F.

Charge-Discharge Cycle Reduces the Life of a Battery- Every battery is subject to a charge-discharge cycle. This considerably reduces the life of a battery. *Higher the discharge, greater is the reduction in its life.* Batteries reach their demise soon with frequent discharges, and hence, battery-based UPS systems are considered as a limited cycle service. The UPS battery warranties are determined by factors such as:

- Duration of discharge
- Number of instances of discharge
- Length of time it takes the batteries to get charged

STATIC UPS SYSTEM RATING & SIZE SELECTION

In order to properly size and select a static UPS system, the load kVA, load power factor, inrush kVA or current, load voltage, number of phases and frequency, and required battery protection time should be determined for the load to be served.

Determining load kVA

In existing installations, the load kVA should be determined by measuring the current with all equipment operating. In three-phase installations, the load current should be measured at each phase. The load kVA can then be estimated as follows:

For single-phase loads: $kVA = VI / 1000$

Where:

- V is the system voltage in volts
- I is the measured current in amperes

For three-phase loads: $kVA = 1.73\ VI/1000$

Where:

- V is the phase-to-phase voltage in volts
- I is the highest measured phase current in amperes

In cases where the load current cannot be measured or when the installation is in the planning stage, the nameplate load (kVA) ratings of individual equipment should be calculated. The total load kVA is then obtained by vectorially adding the individual load kVAs. Also, an approximate but conservative estimate of the load kVA may be obtained by arithmetically adding the individual load kVAs.

Determining load kVA and Power Factor

In existing installations, the load power factor should be determined by actual measurements using a power factor meter. In cases where actual measurements cannot be taken the kVA and power factor of the individual loads should be obtained from the equipment manufacturers' data.

Estimating the load power factor is necessary since the kVA rating and performance parameters of most static UPS system are guaranteed only at a power factor range of 0.8 lagging to unity. The static UPS system kVA capacity and performance parameters are affected at other power factors.

Determining load inrush kVA

Determination of the load inrush kVA is particularly important for static UPS configurations without a static transfer switch and bypass capability. In these configurations, if the load inrush kVA requirements exceed the inverter capability, the inverter will reach the “current limit” mode causing the output voltage to drop. In configurations with a static transfer switch and bypass capability, determining the load inrush current requirements is required for proper selection of overcurrent protective devices for the transfer switch and coordination with other overcurrent protective devices. The load inrush kVA or current in existing installations should be determined by actual measurement using a high speed storage *oscilloscope or oscillograph*. Since all loads are not normally started simultaneously, the inrush kVA or current requirements should be determined by energizing the load with the highest inrush kVA while all other loads are connected. In cases where measurements cannot be taken or when the installation is in the planning stage, data on individual load inrush kVA and duration should be obtained from equipment manufacturers.

Load voltage, number of phases, and frequency

The load voltage and frequency requirements determine the UPS system output voltage and frequency. Three-phase loads require a system with three-phase output regardless of the kVA rating required. However, when all loads are single-phase, a system with single-phase output is preferable up to a rating of 75 kVA. When the single-phase loads are higher than 75 kVA, a system with three-phase output is normally used. In such a case, the loads should be distributed among the three phases to minimize the phase unbalance effects on the inverter.

TESTING

As static UPS is a very complex and critical system, it should be properly tested before being put into use. Before bringing the system to the site it is better to test it at the factory itself. First the steady stale performance of the UPS should be tested. This may be done by varying parameters such as load, line voltage, frequency, temperature, humidity etc. Next dynamic performance tests should be undertaken by tripping the input power line i.e. connecting or disconnecting several units in parallel. The output can also be short circuited to lest the UPS systems capacity to tackle the situation. In addition, by introducing or removing the by pass mode, the performance can be studied.

Another important category is to check the ability of a failed rectifier / inverter unit to isolate itself from the overall system while the UPS is feeding a critical load. Finally, the reliability of the UPS should be tested by operating it under loaded conditions for a long duration.

Similar tests can also be conducted at the customer’s site before connecting the actual load to the system.

PART #2 ROTARY UPS SYSTEMS

This system consists of a synchronous motor driving a synchronous generator with a large flywheel. During normal operation the motor drives the flywheel and the synchronous generator at constant speed. The generator output voltage is regulated by the voltage regulator and the frequency is constant and proportional to the motor power supply frequency. When input power is momentarily lost or degrades, the flywheel supplies its stored energy to the generator and the frequency is maintained within the required tolerance for duration depending on the flywheel inertia. The time interval for which the frequency can be maintained within tolerance is *proportional to the ratio of flywheel inertia to the load for a given speed*.

To keep the system weight low, high speed is required. However, to keep the noise level low, low speed is desirable. Therefore, the system is commonly operated at a speed of 1800 revolutions per minute (rpm) as a trade-off.

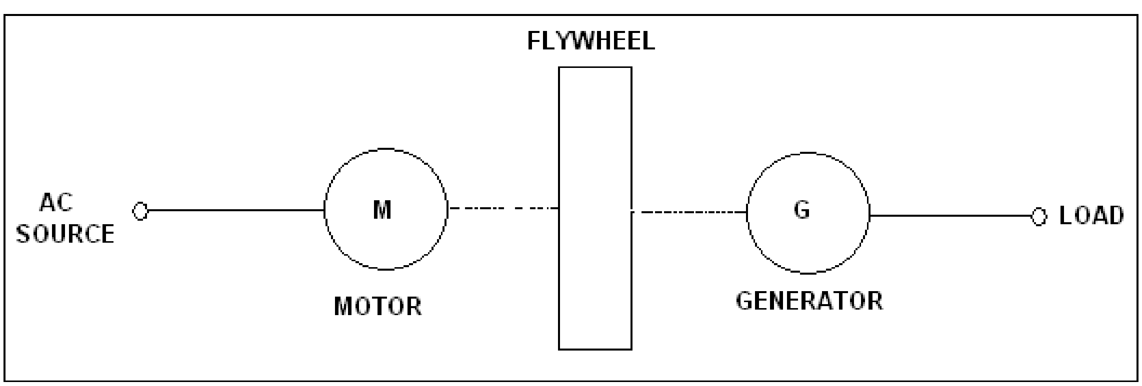
Rotary UPS system configurations

The main building blocks of rotary UPS systems are the synchronous motor, AC generator, and flywheel. In addition to the main building blocks, induction motors, eddy current clutches, batteries, DC M-Gs, and static rectifier/inverters are also used in rotary UPS systems. The building blocks can be assembled in numerous configurations to meet reliability and/or economic considerations. The most common rotary UPS configurations are

1) The inertia-driven ride-through system with a synchronous motor,
2) Inertia-driven ride-through system with an induction motor and an eddy current clutch
3) The battery supported inertia system with a backup inverter

Inertia-driven ride-through system with a synchronous motor

In an inertia-drive ride through system a synchronous motor drives the generator at a constant speed proportional to the power supply frequency. The ratio of the generator number of poles to the motor number of poles should be the same as the ratio of the desired frequency to the power supply frequency.



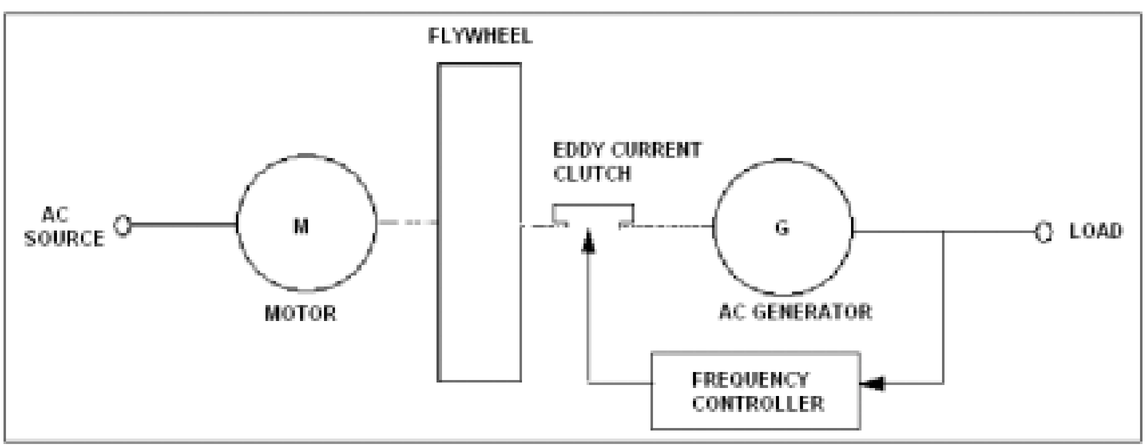
INERTIA-DRIVEN RIDE THROUGH SYSTEM

In this configuration, a synchronous motor is used to maintain a constant speed independent of the load level. However, an induction motor with very low slip (typically less than 0.5 percent) may also be used. With 0.5 percent slip characteristic, the generator output frequency (for a 60 Hz system) can vary from 59.7 Hz at rated load to near 60 Hz at no load.

The main limitation in this configuration is that the ride-through time is normally limited to 0.5 seconds. This makes this configuration suitable only at locations where the power supply has a high reliability and long term interruptions are unlikely. The newer technologies use an induction coupling system rather than the flywheel, which allows for approximately 2 seconds of ride-through while the diesel generator comes on line. This system is used with an asynchronous motor and a synchronous diesel generator.

Inertia-driven ride-through system with an induction motor and an eddy current clutch

This configuration consists of an induction motor which drives a flywheel and an eddy current clutch at a speed essentially proportional to the supply frequency. The generator rotates at a constant speed lower than the motor speed by controlling the slip of the eddy current clutch. The generator output frequency can be maintained at 60 hertz ±0.25 hertz. On loss of the AC input power, the generator receives energy stored in the flywheel. As the flywheel slows down, the slip of the eddy current clutch is reduced so as to maintain the generator frequency at 60 Hz. The generator frequency can be maintained above 59.5 Hz for up to 15 seconds after loss of ac input power. This configuration is most suitable where a backup power source such as a diesel generator or gas turbine is available. The rotary system can supply the loads until the backup source is started and operated to supply the motor. However, the use of this configuration is becoming less common and it is not available from many manufacturers.

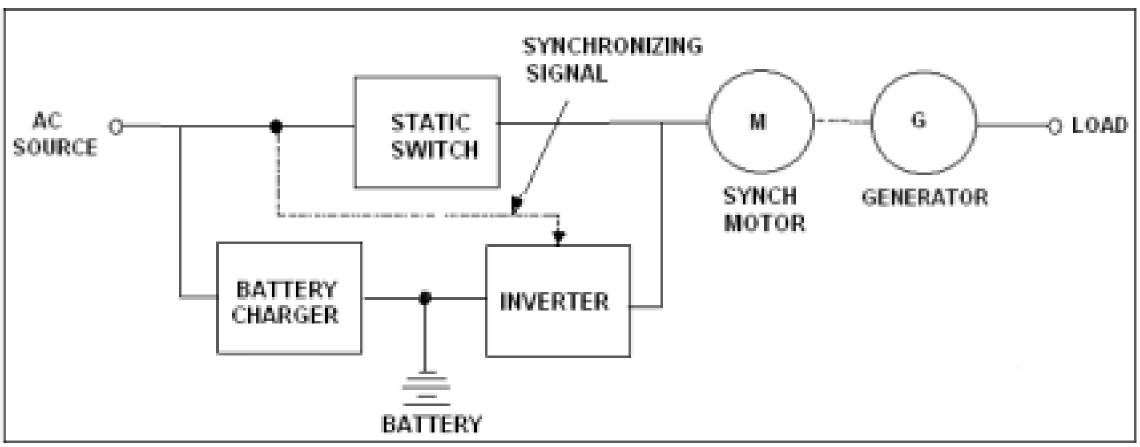


INERTIA DRIVEN RIDE THROUGH SYSTEM WITH AN INDUCTION MOTOR AND AN EDDY CURRENT CLUTCH

Battery supported Motor Generator (M-G) set

The battery supported M-G system with a backup inverter is made up of a synchronous M-G set with the addition of a rectifier/inverter, batteries, and a static switch. During normal operation, the synchronous motor drives the synchronous generator and provides filtered power. Upon loss of the AC input power to the motor, the battery supplies power to the motor through the inverter which drives the generator. The batteries provide energy to the system during the transition from normal to emergency operation. During normal operation, the static switch is conducting and 95 percent of the required power is supplied to the motor from the AC source. The remaining 5 percent power is supplied through the rectifier/inverter while the battery is float charged. The inverter is kept operational at this low power level to ensure that it remains operational and can supply full power in the event of degradation or loss of the AC source.

Upon loss of the AC source or deviation of its frequency and/or voltage from acceptable limits required to maintain the generator output, the static switch is automatically blocked and power is supplied from the battery to the motor through the inverter. Upon restoration of the AC source, the static switch automatically conducts and the system reverts to normal operation. This configuration provides conditioned, isolated, and uninterrupted power.



BATTERY SUPPORTED MOTOR- GENERATOR (M-G) SET

Rotary systems with a transfer switch to a bypass source

Like static UPS systems, rotary systems can be provided with a transfer switch to transfer the load to an alternate source upon loss of the generator output. However, unlike the static UPS inverter, it is not practical or economical to synchronize the generator to the alternate source. Therefore, the transfer may occur in "out-of-synch" mode and may subject the connected loads to undesirable transient over voltages. Therefore, although the addition of a transfer switch can increase the availability of power supply, live transfer is not recommended in rotary systems. Also, less costly electromechanical switches may be adequate for this purpose.

Paralleling of redundant rotary systems

Redundant rotary systems may be connected in parallel to provide higher capacity and/or to increase the reliability. However, due to the difficulty of synchronizing the generators to one another, switching the individual generators for parallel operation should be performed without the loads being connected to avoid subjecting sensitive equipment to high voltage transients during switching.

ROTRAY UPS COMPONENTS CHARACTERISTICS

Motor and generator ratings and performance characteristics are standardized by the National Electrical Manufacturers Association (NEMA) in ANSI/NEMA Publication MG-1, 1978.

MOTORS

In a rotary UPS system an AC motor is used to convert electrical energy to mechanical energy for driving an AC generator and a flywheel. Both synchronous and induction motor types may be used. DC motors may also be used in rotary systems with a storage battery for back-up power. In the following paragraphs, only the motor characteristics relevant to rotary UPS applications are addressed.

Induction motors

Induction motors are of the squirrel cage or the wound rotor type. It is the three-phase cage motor type that is used in rotary UPS applications. The relevant characteristics of a cage motor are as follows.

1) The motor speed is depended on the load level and essentially proportional to the power supply frequency. For a motor with 5 percent slip, the speed may increase by up to 5 percent of the rated speed from rated load to no load.

2) The speed variations are lower for low slip motors.

3) When energized, the motor draws a starting current as high as 6.5 times the rated current for duration of 2 to 10 seconds or longer depending on the load inertia.

4) The induction motor power factor is approximately 0.8 lagging.

5) The NEMA rating structure of continuous duty induction motors is based on horsepower output, maximum ambient temperature for which motor is designed, speed at full load, frequency, number of phases, voltage, full load current, and lock rotor (starting) kVA.

Synchronous motors

The relevant characteristics of a three-phase synchronous motor are as follows:

1) The motor speed is independent of the load and is directly proportional to the power supply frequency.

2) The starting current and starting duration of a synchronous motor are slightly less than those of a comparable induction motor.

3) A synchronous motor can be either self-excited or externally excited.

4) The synchronous motor power factor can be changed from lagging to unity or leading by adjusting the field or exciting current.

5) The NEMA rating structure of continuous duty synchronous motors is based on horsepower output, maximum ambient temperature for which motor is designed, speed at full load, frequency, number of

phases, voltage, full load current, field current, excitation voltage, power factor, and locked rotor (starting) kVA.

DC motors

DC motors are classified according to the method of excitation used as shunt excited, series excited, and compound excited. The shunt excited DC motor is the most suitable in rotary UPS applications and has the following characteristics:

1) The motor speed is dependent on the load level. The speed may decrease by up to 5 percent of the rated speed from no load to rated load.

2) The motor speed can be easily adjusted by varying the shunt field current through the use of a rheostat.

3) The motor can be operated as a generator by applying mechanical input to the shaft.

4) The NEMA rating structure of continuous duty DC motors is based on horsepower output at base speed, maximum ambient temperature for which the motor is designed, base speed at rated load, armature voltage, field voltage, armature load current at base speed, and winding type - shunt, series, or compound.

GENERATORS

In the following paragraphs, only the generator characteristics relevant to rotary UPS applications will be discussed.

Synchronous generators

The relevant characteristics of a three-phase synchronous generator are as follows:

1) The generator frequency is directly proportional to the prime mover speed. Controlling the output frequency is accomplished by controlling the prime mover speed.

2) The output voltage can be regulated by varying the field current, i.e., excitation level.

3) The generator rated power factor is normally 0.8 lagging.

4) The generator has a limited load unbalance capability; severe unbalance can result in overheating.

5) The generator can supply a maximum current of 6 to 7 time’s rated RMS current for a few cycles and 3 to 4 times rated RMS current for a few seconds.

6) The output voltage harmonic content is typically less than 5 percent.

7) The NEMA rating structure at synchronous generators is based on kVA output, output power (kW), power factor, maximum ambient temperature for which the generator is designed, speed, voltage, full load current, number of phases, frequency, excitation current, and excitation voltage.

DC generators

Similar to DC motors, DC generators are classified as shunt excited, series excited, and compound excited. The relevant characteristics of dc generators are as follows:

1) The generator output is essentially ripple free power.
2) The output voltage can be precisely held at any desired value from zero to rated by controlling the excitation level.
3) The generator can be operated as a motor by applying DC power to its armature.

Exciters

Exciters are used to create the magnetic field on the generator. They can be broadly classified as static and rotary.

1) In a static exciter all components are stationary and are mounted outside of the machine frame. The synchronous machine field coils are connected to commutator rings, and brushes are used to connect the field coils to the excitation power source.
2) In a rotary exciter, some of the components are rotating and are mounted either on the synchronous machine shaft or externally. Also, in a rotary exciter a commutator ring and brushes may be required or the system may be brushless. Brushless type exciters are more commonly used now due to their lower maintenance requirements.

However, selection of the exciter type is largely up to the manufacturer to meet the performance requirements.

FLYWHEEL

A flywheel is used in a rotary UPS system as an energy storage device. The flywheel is coupled to the M-G shaft and supplies stored energy to drive the generator upon momentary loss of the motor output. In addition, it acts to stabilize the generator frequency by maintaining the rotational speed following transient frequency variations at the motor power supply or sudden load changes.

The flywheel inertia is selected such that the stored energy is sufficient to supply the generator while operating at rated power for a duration not exceeding 0.5 second while keeping the speed from falling to maintain the frequency drop to a maximum of 0.5 Hz. The flywheel inertia plus the inertia of the coupled motor(s) and generator make up the total inertia of a rotary UPS system. The flywheel inertia is usually more than 95 percent of the total inertia and the motor's and generator's inertias can be neglected. The required flywheel inertia (WK^2) can be calculated as follows.

$$WK^2 = H \frac{kW \, x 10^6}{(0.231)(n)} \quad (lb - ft^2)$$

Where:

- kW = generator rated power (kW)
- n = generator rated rotational speed (r/min)

The inertia constant (H) is determined based on the required ride-through time and minimum frequency as follows.

$$H = t \Big/ \left[1 - \left(\frac{F_{\min}}{f_r} \right)^2 \right]$$

Where:

- t = required ride-through time (s)
- F_{min} = minimum frequency required at the end of the ride-through time (Hz)
- f_r = generator rated frequency (Hz)

Theoretically, a flywheel can be selected to provide any ride-through time. *However, practical and economical considerations limit the ride-through time to around 0.5 second.* High flywheel inertia causes a long motor starting time. During the starting time, the motor's high starting current can cause unacceptable or excessive motor heating. Also, due to the flywheel's heavy weight and the long starting time, special bearings and lubrication methods may be required.

Advantages and disadvantages of rotary UPS systems

The rotary UPS system has both advantages and disadvantages that should be considered at the time of selection.

Rotary advantages

1) The rotary system has low output impedance, which makes it able to supply higher fault currents to operate a circuit breaker during fault conditions. They provide total isolation of sensitive loads from power supply system transients. *Its output voltage is less susceptible to harmonic distortion as may be caused by non-linear loads.*
2) They provide disturbance free uninterrupted power.
3) Systems without storage batteries have a low initial cost. Efficiency is higher than comparable static UPS systems.
4) The rotary UPS systems have higher tolerance to adverse environments.
5) They do not cause power supply system voltage distortion. High ratings, e.g., above 1000 kVA can be built in the rotary UPS design.
6) A rotary system has a lower number of components than a comparable static system and hence has a lower failure rate.

Rotary Disadvantages

While there are several advantages to the rotary UPS, it does have some short comings. Some of them are that

1) They operate at high sound levels unless equipped with special silencing enclosures.
2) They require more maintenance and long repair times.
3) They require special foundations.
4) Their installation is more complex.
5) They do not easily lend themselves to future expansion, paralleling, or reconfiguration.
6) Their performance requirements and configurations are not commonly standardized. Fewer manufacturers produce rotary UPS systems as compared to static UPS systems.
7) The rotary UPS has a short backup time and requires either a battery or backup diesel generator for longer backup power.

ROTARY UPS SYSTEM SELECTION CRITERIA

Selection of a rotary UPS system should be in accordance with certain criteria. The system output voltage and frequency shall be as required by the loads. The output should preferably be three-phase except for small systems (5 kVA and smaller) where single-phase systems may be used.

The system rated kVA at the specific site shall be equal to the load kVA plus a 10 to 15 percent margin. The system shall be capable of supplying the load inrush demand without voltage and frequency deviations beyond the required tolerances.

1) Rotary units are mainly designed for large applications, 125kVA or higher and are generally applied in industrial use. Some reasons for selecting a rotary UPS over a static UPS are to provide higher efficiency, superior fault clearing capability, capability of supplying currents for high inrush loads, and isolation from harmonic distortion generated by non-linear loads in the line.
2) In order to properly size and select a rotary UPS system, the load kVA, load power factor, inrush kVA or current, load voltage, number of phases and frequency, required battery protection time (if battery supported UPS), maximum permissible frequency deviation (if inertia-driven UPS), and required ride-through time (if inertia ride through UPS) should be determined. The maximum permissible frequency deviation and required ride through time is required for sizing the flywheel inertia. The maximum permissible frequency deviation should be the maximum deviation tolerated by the most sensitive load. Balance all information can be determined in the same manner as described in case of static UPS systems.
3) The inertia-driven ride-through configuration should be considered at sites where the power distribution system has a high reliability and long duration interruptions are not frequently experienced.

4) The battery supported inertia configuration should be considered at sites with frequent long duration power interruptions. The battery protection time shall not be less than one minute and shall not exceed the maximum time the load can be operated with the loss of the environmental support equipment.

Rotary UPS systems are typically outdated now days due to rapid advances made in the field of electronics; the static UPS system has become very popular since it has no moving parts. They are more costly for small capacities but become competitive with static units around 300kVA. Rotary units provide complete electrical isolation where the static UPS is limited by the static switch.

PART # 3 SELECTING AN UPS

The process for selecting an UPS consists of eight steps. These steps are:

1) Determining the need for an UPS
2) Determining the purpose(s) of the UPS
3) Determining the power requirements
4) Selecting the type of UPS
5) Determining if the safety of the selected UPS is acceptable
6) Determining if the availability of the selected UPS is acceptable
7) Determining if the selected UPS is maintainable, and
8) Determining if the selected UPS is affordable

The last four steps may require repeating if the UPS does not meet all of the requirements. This process does not and cannot provide a “cookbook solution.” Each facility has unique requirements for emergency and standby power. These requirements include the reliability of the prime power source, the nature of the work done, local and state regulations governing emergency power, etc. The process does not give a single solution that is applicable to all cases. It is hoped, however, that it provides the framework for selecting an UPS for any facility and illustrates the many factors that go into the decision process in making the UPS selection.

Determine need

Determining the need for an UPS is mainly a matter of evaluating the way in which a facility is used, as well as knowing whether local, state, or federal laws mandate the incorporation of an UPS.

Determine the purpose

An UPS may be needed for a variety of purposes such as lighting, startup power, transportation, mechanical utility systems, heating, refrigeration, production, fire protection, space conditioning, data processing, communication, life support, or signal circuits. Some facilities need an UPS for more than one purpose. It is important to determine the acceptable delay between loss of primary power and availability of UPS power, the length of time that emergency or backup power is required, and the criticality of the load that the UPS must bear.

Applications such as hospital life support and safety, aircraft tracking and landing, and certain production process controls and data processing cannot tolerate any loss of power, no matter how short the period of time, without loss of life or revenue. Other applications like refrigeration, heating, and cooling may tolerate loss of power for several minutes (or longer) without any adverse effects. For data processing equipment, it may be necessary to maintain power until the equipment can be shut down in an orderly manner. All of these factors play into the sizing of the UPS and the selection of the type of the UPS.

Determine the power requirements

After determining the specific purpose(s) for an UPS, the next step is to determine the facility power requirements. This task is often laborious but is essential because it sets the stage for the remainder of the selection process. Undefined power requirements, or oversight of any initial conditions, could result in the selection of a system that is not capable of meeting the needs of the facility, costly budget overruns, and delays in completing the project.

Once the power requirements are defined by adding all critical loads, the next step is to determine how much (if any) to oversize the unit. Over sizing serves two purposes. First, it provides the capability to efficiently and effectively handle surges in power requirements due to peak demands caused by starting machinery, switching power supplies, etc. Secondly, it provides for growth. A general rule of thumb in over sizing is to increase the initial power requirement by 30 percent.

Select the Type of UPS

Selecting a particular type and configuration of an UPS depends on many factors that must be considered and weighted according to a facility's particular requirements. These factors include the purpose of the UPS, the required power, cost, safety, environmental, availability, and maintenance.

Determine safety

It must be determined, if the safety of the selected UPS is acceptable. The UPS may have safety issues such as hydrogen accumulation from batteries, or noise pollution from solid-state equipment or rotating equipment. Safety problems associated with lead-acid batteries include spills of sulfuric acid, potential explosions from the generation of hydrogen and oxygen, and the generation of toxic gasses such as arsine (AsH_3) and stibine (SbH_3). All of these problems can be satisfactorily handled with the proper safety precautions. National Fire Protection Association (NFPA) 70, National Electrical Code (NEC), provides guidance on battery room ventilation. Wearing face shields and plastic/rubber aprons and gloves when handling acid is recommended to avoid chemical burns from sulfuric acid. Precautions must be routinely practiced to prevent explosions from ignition of the flammable gas mixture of hydrogen and oxygen formed during overcharge of lead-acid cells. The gas mixture is explosive when hydrogen in air exceeds 4 percent by volume. A standard practice is to set warning devices to alarm at 20 to 25 percent of this lower explosive level. Hydrogen accumulation is usually not a problem, if good air circulation around a battery is present. If relatively large batteries are confined in a small room, an exhaust fan(s) should be used to constantly vent the room or should start automatically when hydrogen accumulation exceeds 20 percent of the lower explosive limit. Finally, the materials used in the battery container should be fire retardant. These issues may be addressed through proper precautions or may require a selection of a different UPS.

Determine availability

In managing a facility, the availability of equipment and systems is of the utmost concern. Simply stated, availability is the amount of time a piece of equipment is available to perform its function divided by the total time the equipment is needed. It is also defined as “uptime” divided by “total time.” Thus, if an air conditioner is required 12 hours each day, the availability would be 90 percent if it is out of commission an average of 1.2 hours each day. Normally, the required availability for UPS is 98 percent. It should be noted that the many critical facilities require a reliability level of 99.9999 percent. The availability of an UPS may be improved by using different configurations to provide redundancy.

Availability is a function of reliability and maintainability. The inherent or designed-in availability is usually expressed as follows.

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

Where:

- Ai is inherent availability
- MTBF is mean time between failure (a measure of reliability)
- MTTR is mean time to repair (a measure of maintainability)

Reliability is the probability that the item will perform as intended for a specified period of time, under a stated set of conditions. It can be expressed in terms of the number of failures in a given time (the failure rate), or as the time between failures (for repairable items), or time to failure (for “one-shot” or non-repairable items.

Maintainability is defined as the relative ease and economy of time and resources with which an item can be retained in, or restored to, a specific condition. It can be expressed as the probability that an item can be restored to operational condition in a stated time, the number of repairs that can be made in a specific time (repair rate). From the equation for Ai, it is obvious that availability can be increased by increasing MTBF or reducing MTTR. For example, assume the MTBF and the MTTR of a single UPS unit are 500 hours and 20 hours, respectively. The inherent availability of a single unit configuration would be:

$$A_i = \frac{500}{500 + 20} = 0.962$$

The inherent availability of a two-unit configuration where only one unit is required would be:

Ai = A1 + A2 – (A1 x A2) =0.999

The inherent availability of a two-unit configuration where both units are required would be:

Ai = A1 x A2 = 0.925

The availability could be increased by increasing the reliability or reducing the MTTR. The reliability could be increased by selecting a more reliable unit, derating the unit (i.e., use a unit capable of providing more power than needed - when used, it will be operating below its capacity thereby reducing stresses), or use redundancy. MTTR could be decreased by selecting an inherently more maintainable system or perhaps by improving diagnostics, training, or procedures.

Determine maintainability

Maintenance of the unit is important in assuring the unit's availability. If the unit is not properly cared for, the unit will be more likely to fail. Therefore, it is necessary that the maintenance be performed as required. If the skills and resources required for the maintenance of the unit are not available, it may be necessary to select a unit requiring less maintenance.

Determine if affordable

The selected UPS must be affordable. While this is the most limiting factor in the selection process, cost cannot be identified without knowing the other parameters. For an UPS, the total cost includes the purchase price, installation cost, operating and support costs, and disposal costs. To give you the costing idea, consider the following:

- The cost of any needed auxiliary equipment such as manual bypass switches, cabling and support hardware must also be considered.
- More sophisticated systems having automatic monitoring, switching, and control functions requiring additional components, adding to the complexity and cost of the system(s).
- If the UPS is operated under adverse conditions, availability will suffer. Specific precautions must be taken for dirty, hot, cold, corrosive, explosive, tropical and other adverse conditions.
- Additional air conditioning might be required for the UPS (or for the facility due to heat loads from the UPS). Rotary units may require additional or special ventilation equipment to purge toxic fumes from working areas.
- Floor units (usually static UPS for computer system backup) may require strengthening of the floor to support their weight.
- Large UPS may require the construction of a separate building to house the unit.
- A rotary UPS or engine generator used in a cold climate will probably require thermostatically controlled lubricating oil, coolant heaters, and radiator louvers.
- Operating and support costs include cost of fuel, maintenance, replacement parts, and taxes.
- Disposal may simply consist of dismantling the UPS and selling the parts to a recycling company or dumping it at an approved refuse site. For example, disposal of lead-acid batteries must be performed according to all federal, state, and local regulations.

- In disposing of spent batteries, the facility manager must ensure that batteries meet all radioactive contamination requirements for uncontrolled release.

A variety of UPS types and configurations can be selected. The costs can vary widely depending on the specific type and configuration selected. It is impractical to provide an all-inclusive cost comparison of all possible combinations of types and configurations. If the above criteria are not met, another UPS system must be selected and these steps re-evaluated.
