Power Supply Considerations For Digital Control Systems

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KEYWORDS

Digital Control Systems; Critical AC; Vital AC; Uninterruptible Power Supply Systems; Control System Power Supplies

ABSTRACT

With the conversion of existing analog instrumentation and control systems to digital systems, the need for careful consideration and planning of power supply systems has become critical to the success of these systems. Instrumentation and control systems, especially microprocessor based systems, cannot tolerate unanticipated power system disturbances. Such disturbances could result in the failure of equipment to perform its intended design function in addition to loss of plant data. This is especially true for nuclear power plants where instrumentation systems are required for safely-shutting down the reactor, mitigating the consequences of an accident, and performing post-accident analysis. This paper will address the most important issues which must be considered in the design, operation and maintenance of power supply systems, as summarized below.

Power Quality – Most digital control systems are provided with power conditioning; however the equipment selected to provide power for these systems should meet an established set of minimum requirements for voltage regulation and noise suppression to ensure that the output of the UPS meets the manufacturer’s requirements for the Digital Control System.

Redundancy – All digital control systems should have more than one power supply, at least one of which will allow for an orderly shutdown in the event of a loss of offsite power.

Diversity – Digital control systems which provide redundant design functions should be designed such that failure of a single power supply will not result in multiple failures and/or a loss of more than one system.

Planning – Planning prior to the installation of digital control system upgrades to address the total amount of power needed and shutdown load requirements is essential to ensure reliable operation. Sizing of the batteries for these systems should include adequate allowance for future load expansion plus a design margin which includes the effects of temperature and aging, in order to ensure that the UPS system will adequately supply the anticipated load even near the end of the battery's rated design life.

Maintenance – Adequate maintenance and surveillance testing of UPS systems should be performed at regular intervals and necessary repair or replacement of components and equipment completed in order to ensure proper operation when needed.

INTRODUCTION

Instrumentation and Controls in most power generating stations have long been provided with either DC or Regulated AC power backed up by a battery system as a means of insuring reliable operation. The advent of digital systems with microprocessor-based control systems has further increased the need for reliable sources of power to these systems, especially for shutdown systems, data collection, and sequence of events applications. The size and configuration of these power supply systems is dependent primarily on the criticality of the system and the need for uninterrupted power.

There are many factors involved in determining the type of power supply which should be used for digital control systems. This paper focuses primarily on the considerations which must be given attention when determining the type and size of UPS needed for such systems. These include power quality, degree of redundancy required, planning to accommodate existing and future UPS requirements, and the necessity to perform maintenance to ensure their success.

POWER QUALITY

Based on EPRI Report TR-1016731[4] one of the most reported causes for common cause failures of non-Safety Related digital control systems are EMI induced disturbances and power supply transients and failures. Power supply transients can include supply voltage surges or spikes, frequency deviations and noise induced by harmonic content.

VOLTAGE AND FREQUENCY STABILITY

Results of testing documented in EPRI Report TR-1001072[5] revealed that programmable logic controllers (PLC's) are most susceptible to the depth, duration and likelihood of voltage sags. Disturbances to the power system voltage and frequency can result from lighting, short circuits, and switching of loads such as capacitor banks all of which can result in transient voltage surges and spikes. It was found that the duration of voltage sag can affect the performance of the PLC and result in premature system shutdown in some cases. Also even momentary voltage surges can cause malfunction of input and output circuits, especially if the PLC power supply is also used for sensing voltage. It was also found that a UPS inverter which produced a square wave output was not compatible with three of five PLC's which were tested but that a UPS inverter that produced a true sine wave output effectively mitigated voltage-sags [5].

POWER QUALITY REGULATION AND MONITORING

The addition of a constant voltage transformer (CVT) to the PLC's power supply was found to be very effective in improving the ability of the PLC to ride through such voltage surges and transients. UPS systems that are to supply equipment that includes a digital control system should be designed to produce a true sine wave output in order reduce the impact of harmonics. Some battery chargers are not designed to operate as a stand-alone rectifier for an inverter and must be always connected in parallel with a set of batteries in order for the UPS inverter to properly compensate for any transients through adequate frequency control and voltage regulation of its output.

ELECTROMAGNETIC INTERFERENCE (EMI)

Electromagnetic Interference (EMI) and power surges have been identified to have significant and harmful affects upon the performance of safety related equipment in nuclear power plants. This is especially true for digital control systems where noise from EMI can be misinterpreted as legitimate logic signals. NRC Regulatory Guide (RG) 1.180[6] was issued to address the effects of EMI/RFI and power surges for safety-related I&C systems in nuclear power plants and endorses acceptable design, installation and testing practices. It is critical that the digital control system equipment be tested in accordance with the standards recommended in this guideline. UPS equipment should meet minimum standards for radiated and conducted emissions in order to ensure electromagnetic compatibility with the control systems to which they supply power. EPRI TR-102323 [9] provides guidelines for data collection, testing and practices to ensure electromagnetic compatibility (EMC) in digital control systems in nuclear power plants and meets the requirements specified in RG 1.180. In addition surge suppression should be installed on all power and control circuits surrounding these systems in order to ensure the elimination of unwanted disturbances or noise.

REDUNDANCY AND DIVERSITY

POWER SUPPLY CONFIGURATION

All digital control systems should be fed from an AC power source that will allow for orderly shutdown and data retention in the event of a loss of normal AC power. The need for UPS-backed power is primarily dependent on the criticality of the control system and the availability of sufficient emergency power until normal AC power can be restored. Control systems with a single AC power feeder should always be powered from a UPS-backed source and those with multiple redundant power supplies should be powered from at least one AC power source which is UPS-backed. Consideration should also be given to supplying the UPS for critical control systems from a diesel generator-backed source, especially for those systems that are needed for safe shutdown and subsequent monitoring following a loss of normal AC power.

MULTI-TRAIN CONTROL SYSTEMS

Power supplies to multi train systems should be powered from at least one power supply which is UPS backed. Where operation is needed during a loss of normal AC power, such as in shutdown systems, data loggers, and vital computers and alarm systems, consideration should be given as to the need of a second UPS-backed source in order to maximize reliability of the system to perform it's necessary design function by eliminating single point failure in the event of a loss of normal AC power. In addition, the power feeders to multiple control systems which provide redundant functions should be designed such that failure of a single feeder will not result in multiple failures and/or a loss of more than one system. Redundant trains or systems should not be powered from the same UPS or normal AC power source such that loss of a single source would result in a loss of both control systems.

PLANNING

Planning prior to the installation of digital control system upgrades to address the total amount of power needed and shutdown load requirements is essential to ensure reliable operation. Sizing of the batteries for these systems should include adequate allowance for future load expansion plus a design margin which includes the effects of temperature and aging, in order to ensure that the UPS system will adequately supply the anticipated load even near the end of the battery's rated design life.

EXISTING UPS SYSTEMS VERSUS NEW UPS

The following should be considered in deciding whether to use or upgrade an existing UPS system or install a new UPS system specifically for the application:

Availability - A critical review should be performed of the availability of sufficient power to fully supply the new control system, auxiliary systems and associated indication. The result should ensure that all necessary power required is available, in addition to a design margin that will allow for expansion of the control system to maximum or an acceptable level of its capacity. If the addition of the new control system results in a low or inadequate margin for expansion, consideration should be given to replacing the existing UPS system and batteries or install a separate UPS capable of carrying the load of the new control system in addition allowing for future expansion.

Power Quality - Older UPS systems often have irregular wave forms and contain a lot of high frequency harmonics that, while tolerated by the old analog systems, may be detrimental to the operation of a digital system. The requirements of the planned new systems should be compared to the performance characteristics of the existing UPS, if it is to be used as the power supply for the new system.

Condition of Existing Equipment – The condition and the age of existing equipment, especially batteries should influence whether or not it is more cost effective to install a new system or use the existing one. With older battery systems whose lifetime is nearly expended, or UPS systems that require replacement of components, it may be more economically feasible to install a new system with enough capacity to handle the additional load of the new control system(s).

Space Requirements – Consideration should be given as to the space available to install a new UPS system including separate battery cabinets or racks. This will also affect the type of batteries selected as batteries that have vented lead acid cells require much more space than stackable cells.

UPS SELECTION

Once a decision has been made to install a new UPS system, the decision must be made on the UPS configuration. There are primarily two configurations presently in use for vital AC systems.

SINGLE UNIT FLOAT CONFIGURATION

This configuration uses an inverter that is connected to a battery and charger (refer to Figure 1). As long as normal AC power is present, the charger maintains the charge on the battery system and supplies DC power to the inverter, which then supplies the load, usually though a Static Switch that transfers the load from the inverter to an alternate AC source in the event of a problem with the inverter. The system may or may not be provided with a Manual or Maintenance Bypass Switch which can be used to temporarily feed the load during maintenance activities on the batteries, charger, inverter or the static switch. One advantage of this configuration over a single unit rectifier configuration is that the battery has the effect of acting as a buffer to remove excess DC ripple current from the charger which could otherwise lead to damage of the inverter due to overheating [1].

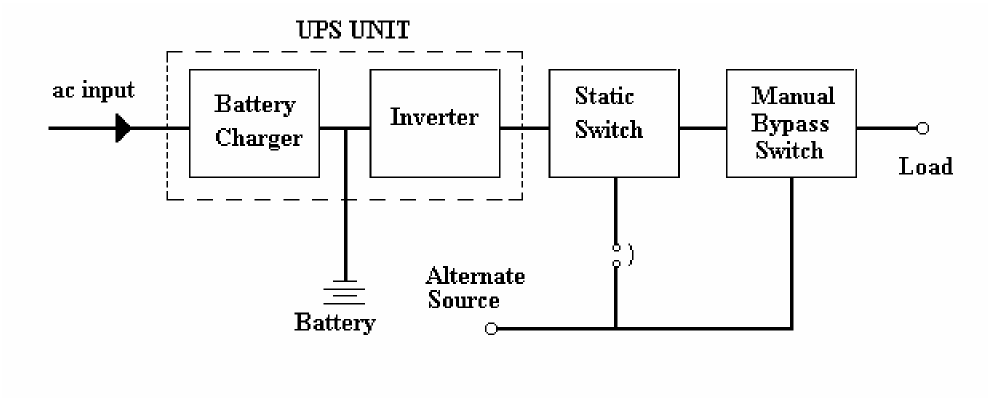

Figure 1 Single Unit Float Configuration UPS System [1]

SINGLE UNIT RECTIFIER CONFIGURATION

This configuration commonly used in both nuclear and fossil power plants for critical AC systems. The primary difference between this configuration and the above is that there is a separate rectifier which supplies power to the inverter which in turn supplies power to the load. Note the installation of a blocking diode between the output of the rectifier and the battery charger output. This prevents the rectifier from attempting to also charge the batteries and any other DC loads that are connected to the same battery or DC buss. The rectifier for the inverter is specifically designed to supply power to the inverter and is usually rated much smaller than the charger connected to the batteries and the rest of the DC system. The rectifier in this type of UPS is usually designed to supply power to the inverter without being connected to a battery; however a better input filter is required to eliminate excess ripple as the tank capacity of the battery to smooth out ripple is lost [1].

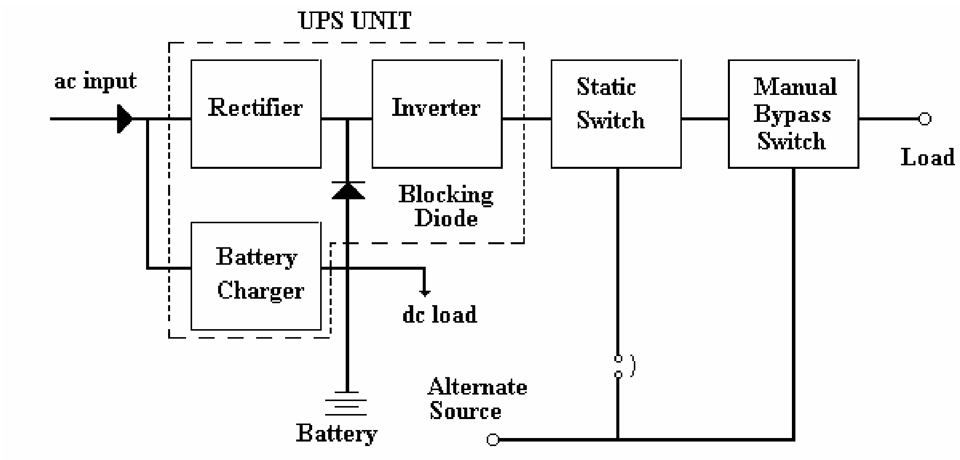

Figure 2 – Single Unit Rectifier Configuration [1]

The type of UPS system to be used depends, among other factors, on the need for continuous uninterrupted power to the control system, power quality requirements and the tolerance of the existing power supply system to harmonic currents created by some UPS equipment. There are several types of UPS systems which are briefly described below. The first two systems are usually smaller in size and commonly used for desktop computers, network servers and equipment. They are not recommended as a reliable power supply for instrumentation or control systems.

Standby UPS - In a Standby UPS system, power is normally supplied from the normal AC power, which also feeds the charger to a set of batteries that are connected to the inverter. In the event of power failure, a transfer switch connected to both the normal AC input and the inverter transfers the load to the inverter output. Thus the inverter only supplies the load after power has been lost and there is a momentary delay because of the operation of the transfer switch [8].

Line Interactive UPS - The primary difference in this UPS from the Standby UPS is that the inverter is always connected to the load and the transfer switch is connected between the normal AC power source and the inverter/charger. When normal AC power is present the inverter/charger acts in reverse to both supply power to the load and charge the batteries. If normal AC power is lost the transfer switch opens and the battery supplies the inverter [8].

Standby Ferro resonant UPS –The output of this UPS is connected to a Ferro resonant transformer which has two power connections one from the transfer switch and one from the inverter. The inverter is normally unloaded as the normal AC supplies the load via a transfer switch between the power supply and the Ferro resonant transformer. In the event of a loss of normal AC, the transfer switch opens and the inverter supplies the load. The Ferro resonant transformer has additional windings which are connected to capacitors and inductors which effectively “tune” the transformer and enable it to perform voltage regulation and wave-shaping, including isolation from AC power transients [8].

Double Conversion On Line UPS – In this type of UPS, the AC source supplies both the charger and a separate rectifier which supplies DC power to the inverter. The inverter is continuously supplying power to the load. If normal AC power is lost, the batteries supply the DC to the inverter; hence there is no interruption of AC power to the load [8]. This type of UPS system is commonly used for vital AC power to instrumentation and control systems in power plants.

The majority of UPS systems in nuclear power plants use either a Ferro resonant type or phase-width modulation (PWM) type inverter. In PWM technology, switching of multiple stages of either SCR bridges or insulated gate bipolar transistors (IGBT) are used to generate a stepped-waveform that approximates a sine wave. The output is controlled by varying the repetition rate and width of the pulses in each stage which also enables the inverter to perform both wave shaping and voltage regulation [1]. At the input to inverter is either a power factor correction circuit (PFC) or voltage source converter (VSC) to boost the input voltage. This feature also results in lower total harmonic distortion (THD) at AC input to the rectifier which minimizes the impact on the AC power distribution system. The output of these UPS systems has a lower THD (< 4%) and they are more efficient than older systems because of the elimination of the losses in the Ferro resonant transformer at the output [10].

UPS SIZING CONSIDERATIONS

The following factors should be considered in determining load requirements, whether evaluating the capacity of an existing UPS system or determining the size of a new UPS system:

- Equipment Power Supplies – The maximum ratings of the power supplies for processors, modules and interface hardware should be used in estimating the system power requirements, in addition to AC power required for all workstations, servers, network equipment, displays in the system which require UPS power. If applicable, the efficiency ratings of these power supplies should be obtained from the manufacturer's specifications and accounted for in determining the estimated load.
- Control System Power Supplies – Most instrumentation and control systems, especially digital systems, are provided with redundant low voltage DC power supplies, in order to prevent system failure in the event of the loss of a single power supply. The output of these power supplies is usually connected to an auctioneering circuit as shown in Figure 3. Both the Normal and Backup AC power feeders should each be designed to carry the full load of a single power supply.

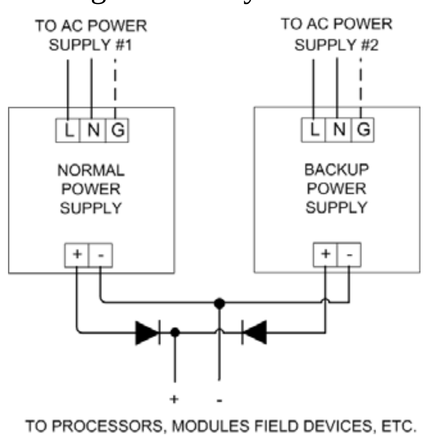

Figure 3 – Typical Auctioneering Circuit for Redundant Low Voltage DC Power Supplies

As noted earlier, at least one of these power supplies should be fed from a UPS. The other power supply may be fed from the normal AC distribution system, diesel generator-backed power or another UPS. It is recommended that the second UPS be powered from a separate AC power source from the primary UPS feeder, and that has its own battery power independent from the primary UPS source. This is especially important for critical control or instrumentation systems.

BATTERY TYPE SELECTION

The term "battery" used in this case refers to a bank or rack of battery cells connected in series. In some systems the cells may also be connected in parallel to provide the required ampacity. The type of batteries used in any UPS system, is dependent upon on the application, power requirements, and environment in which they will be installed, especially the ambient temperature and the desired level of maintenance. There are three basic types of battery systems which can be connected to UPS systems, depending on their application. These are Vented Lead-Acid Stationary Batteries, Valve-Regulated Lead Acid (VRLA) Batteries, and Nickel Cadmium batteries.

VENTED LEAD-ACID STATIONARY BATTERIES

Vented lead-acid stationary batteries are most commonly used for DC backup and emergency power, especially when required in large quantities. The loads supplied by these batteries include breaker control circuits, protective relaying, and Single Unit Rectifier configuration inverters for vital AC power. They can include multiple systems powered by a single battery. Vented lead-acid batteries are typically constructed with transparent or translucent containers that allow electrolyte and internal components to be visible from the outside. This allows monitoring of the cells and adjustment of the electrolyte level. These batteries are continuously vented to the open air, through a flame arrestor on the top of the container which releases hydrogen gas that is produced as a result of charging, especially during an equalization charge. To prevent accumulation of hydrogen, vented lead acid batteries should be installed in a separate room with adequate ventilation. The battery room should also be provided with means of regulating temperature and be designed with provisions for acid retention in the event of spillage.

VALVE-REGULATED LEAD-ACID BATTERIES

There are essentially two types of construction for VRLA batteries: Absorbed Electrolyte construction and Gelled Electrolyte construction. These batteries are commonly classified as "sealed" because it is not possible to access the electrolyte since it is effectively immobilized, so that is not a free liquid, as in a vented cell. This feature minimizes the potential for electrolyte leakage. VRLA batteries are often considered as "maintenance free" however the characteristics of these two types of cells differ significantly. In addition, the application they are used for affects the level of maintenance needed in order to ensure reliability as a backup power source when needed. VRLA batteries are much less tolerant to the effects of high temperature, overcharge, float voltage variations and discharge than conventional lead-acid batteries [2].

Absorbed Electrolyte Construction

In Absorbed Electrolyte, sometimes called absorbed gas mat (AGM) construction, there are highly absorbent glass mat separators wrapped around the plates which hold the electrolyte by capillary action similar to a sponge. These types of batteries have a low cell resistance which makes them capable of higher discharge currents with limited space requirements. The recombination cycle that occurs when batteries are charged produces Oxygen at the positive plate and Hydrogen at the negative plate. In a conventional vented lead-acid cell, this results in a loss of water in the electrolyte which must be periodically replaced. VRLA cells use a process called recombination to replenish the electrolyte. Oxygen must travel from the positive plates to combine with Hydrogen at the negative plates by means of voids or cracks in the electrolyte. There is a pressure relief valve which releases excess gas pressure to limit the internal pressure of the cell. Overcharging or improper regulation of float voltage can result in permanent loss of capacity as the gases released cannot recombine to replenish the electrolyte. If the pressure relief valve malfunctions, this can result in damage and/or loss of capacity. If the valve fails to open, this can result in bulging of the outside container due to over-pressurization. If the valve does not fully close, the cell acts like a vented cell and, since the electrolyte cannot be replaced, this results in a permanent loss of capacity.[2].

Gelled Electrolyte Construction

In gelled-electrolyte construction the electrolyte has been "gelled" by combining it with a silica compound. In addition to turning the electrolyte into a gel, the silicate functions to allow oxygen transport from the positive to the negative plates. The oxygen transport efficiency of these cells improves over time as water loss causes the gel to contract forming microscopic cracks in the gel structure. This along with the silica added to the electrolyte facilitates oxygen transport [2].

NICKEL-CADMIUM BATTERIES

When these batteries are used for large capacity standby service, they are usually the vented (flooded) style. Sealed nickel-cadmium batteries are mostly limited to emergency battery lighting units and small UPS units. One advantage of Nickel-Cadmium batteries is that they are not prone to many of the failure modes as in other types of batteries and they can be used in both high and low temperature environments, as their capacity does not significantly vary with electrolyte temperature. Nickel-Cadmium batteries are not as commonly used in power plants, especially for large capacity requirements, because of their higher cost [2].

SUMMARY

Careful consideration should be given to the type of battery selected for any UPS application. When deciding on the type of battery to be used for different applications, especially for UPS systems that will supply digital control systems, the following should be considered:

Space Requirements - Because of their construction, VRLA batteries have fewer limitations on cell orientation, which allows them to be stacked and they can be used in areas that are not equipped with features to control electrolyte spillage.

Ventilation Requirements – Both conventional vented lead acid batteries and AGM VRLA batteries should be installed in locations with adequate ventilation to avoid buildup of hydrogen in an enclosed area.

Temperature Sensitivity - The capacity of both vented lead lead-acid battery cells and VRLA cells decreases with temperature. However VRLA batteries are much less tolerant of the effects of temperature than vented lead acid batteries in that they exhibit both a loss of capacity as temperature decreases and a loss of life as temperature increases. They are also less tolerant of overcharge, float voltage variation and discharge than vented lead acid battery cells [2]. Therefore the cells of these batteries should be installed in a temperature controlled environment and regular maintenance performed, in order to verify satisfactory condition of both the battery cells and charging system.

Cost Considerations - Nickel-Cadmium batteries are less temperature sensitive, have a reputation for long life and do not have the same problems as VRLA and vented lead-acid batteries. The cost of Nickel-Cadmium batteries is a disadvantage and usually precludes their use in large applications such as power plants.

Maintenance Requirements – Vented lead-acid batteries require regular monitoring of electrolyte levels and cell conditions. VRLA batteries should also be monitored at regular intervals for evidence of swelling or damage, in order to ensure their reliability when needed. In addition the ventilation systems used with these batteries requires maintenance to ensure it is functioning properly to control Hydrogen concentration and is especially critical for lead-acid batteries.

BATTERY SIZING CONSIDERATIONS

In order to properly size the batteries for a new UPS system or evaluate the effect on capacity on an existing system the following parameters must be known:

Minimum and Maximum DC Input Voltage and Efficiency Rating of the UPS Inverter

This information should be included in site documentation and calculations for existing UPS systems or from the manufacturer's specifications for a new UPS system.

Minimum Backup Time Required on Loss of Power

The Minimum Backup time required for the UPS system should be determined by the minimum time the system is required to operate during a loss of power, safe shutdown requirements, and requirements for monitoring of system parameters, alarms and data storage. An allowance for diesel backed power may be made, however for systems which may be critical for safe shutdown and function even upon failure of the diesel generator backed power until normal power is restored. A typical backup time for these systems is 4 hours however critical systems may require a minimum backup time of 8 hours or more.

Discharge Characteristics of the Batteries

The discharge characteristics may be obtained from the manufacturer's discharge tables which show maximum discharge rates for each battery type and number of plates. The specific discharge times and rates are listed for various levels of final battery voltage expressed in volts per cell (VPC) and are given listed by the VPC (usually 1.75 to 1.94 VPC) and includes the ambient temperature (normally 77 °F).

Ambient Temperature Range

The ambient temperature of the battery room or area where the batteries are to be located is required as the capacity of most batteries is a function of cell temperature and must be accounted for estimating the required battery size.

BATTERY SIZING CALCULATIONS

It is recommended that the discharge table be used for a final VPC that is at or just above the minimum input voltage rating of the inverter in order to provide the maximum operating time and compensate for any voltage drop in the battery cables. The battery voltage, inverter rating, efficiency, and power factor (usually assumed at 1.0) are used to estimate the load of the inverter. In addition to the minimum inverter input voltage, the minimum battery voltage should account for the voltage drop of any cables between the battery terminals and the inverter. The voltage drop of the cables should estimated at the maximum inverter DC input current in order to preclude premature shutdown of the inverter prior to the end of the battery's discharge life.

If the battery will supply other DC loads in addition to the inverter, these loads should be also included along with the time duration for which they are required in order to estimate the battery loading during its entire discharge cycle. By combining the loads for the same time period, a Load Profile may be developed showing the battery load during each period of the discharge cycle. The battery load in amps from the Load Profile is used to calculating the minimum number of plates required and allows the user to select a specific a cell size based on the manufacturer's data. The guidelines for sizing a battery are shown in IEEE Standard 485 [7], which also includes a worksheet that can be used for sizing the battery. By inserting the battery load in amps for each time period during the discharge cycle, the number of positive plates per cell can be calculated for each section of the discharge cycle by dividing the load in each section by the Capacity Rating Factor (R_t). The Capacity Factor, expressed in Amps per Positive Plate, is based on the minimum cell voltage and discharge time and may be obtained from the battery manufacturer. The sum of positive plates in each section is then totaled and the result multiplied by factors for temperature and aging. Table 1 in IEEE 485 lists the Temperature Correction Factor for vented lead-acid batteries with a nominal Specific Gravity of 1.215 at electrolyte temperatures between 77 °F (25 °C) and 125 °F (51.7 °C). These factors can also be used for these batteries with a specific gravity of up to 1.300. In addition to temperature correction, the minimum number of plates should be multiplied by a factor of 1.25 to allow for capacity reduction due to aging and ensure the battery will be able to deliver the required capacity near the end of its service life. It is recommended that in addition to these factors, the Design Margin be increased by 10-15% to allow for future expansion [7]. The resulting minimum number of positive plates is used to calculate the total number of plates required (2n +1) and select the cell type and size from the manufacturer's data.

In lieu of using the worksheet in IEEE 485, battery manufacturers usually provide an on-line application on their websites, which can be used to determine the minimum size battery for various applications. There are also computer based applications commercially available which can perform battery sizing calculations. In addition, they can provide a detailed profile of the battery and inverter input voltage during the battery's discharge cycle which also includes the voltage drop of any connecting cables. In either case, it is important to remember that it is much more cost effective to adequately size a battery for future or unexpected loads when it is installed than to attempt to add a second UPS to an existing battery or increase in the size of the existing batteries because of insufficient available capacity.

ALLOWANCE FOR FUTURE LOADS

In addition to accounting for the load of the new control system and existing loads that to be powered from the UPS system, careful review should be performed and adequate allowance made for any future systems or expansion of the existing system that will result in additional UPS load. This is critical in order that the UPS is adequately sized, or in the case of an existing UPS, ensure that there is sufficient battery capacity remaining to accommodate the future loads. It is important to also allow for the effects of temperature and aging of the batteries, which results in a degradation of their capacity. This ensures that the battery will deliver its full capacity for the entire time it is required to provide backup power to the UPS.

EXAMPLE

The following is an evaluation performed for a non-safety related digital control system which included 2 processing cabinets, 2 client servers, 2 displays, a non-redundant terminal server, and associated network interface equipment. The existing inverters (7.5 KVA) were determined to be inadequate to supply the load of the new control system which eliminated using either of these inverters. In addition, reconfiguring the power feeders from dual UPS feeds one UPS source and one non-UPS source also resulted in a negative margin on one of the existing batteries and a relatively low remaining margin on the other.

Load Addition UPS/Batteries	Existing UPS No. 1	Existing UPS No. 2
Total AC Load Change (Excluding Future Loads)	73.8 Amps	73.0 Amps
Estimated DC Load Change on Battery	73.8 Amps DC	73.0 Amps DC
Existing Load on Battery	455 Amps DC	269.8 Amps DC
Revised Load on Battery (4 Hours)	528.8 Amps DC	342.8 Amps DC
Estimated Margin Remaining on Battery	-7.05%	7.65%

Table 1- Evaluation of Existing UPS Systems and Batteries (Original Configuration)

Two new 15 KVA UPS systems were proposed which would supply the load of the proposed upgrade and allow for future system plus a sufficient margin for additional expansion. A newer style UPS which uses phase width modulation (PWM) in the inverter in lieu of a regulating transformer which should result in better efficiency and performance. The type of batteries used will either be VRLA batteries with AGM construction, having a rated life of twenty years, or a less costly set with gelled electrolyte construction having a rated life of 10 years. In either case, it is expected that both new 15 KVA UPS systems should be able to supply the load of the new digital control system and the future system and also have design margins of greater than 20% in each case.

Estimated Load	New UPS 1A	Group 1 Non-UPS Load	New UPS 2A	Group 2 Non-UPS Load
Processors & I/O Group 1	20.4 Amps	0.0 Amps	20.4 Amps	0.0 Amps
Processors & I/O Group 2	0.0 Amps	19.0 Amps	0.0 Amps	19.0 Amps
Operator Display Client Group 1	12.5 Amps	0.0 Amps	0.0 Amps	12.5 Amps
Operator Display Group 1	1.5 Amps	0.0 Amps	0.0 Amps	1.5 Amps
Non-Redundant Server/Network Equipment	20.4 Amps	0.0 Amps	19.6 Amps	0.0 Amps
Future Group 1 Equipment	25.0 Amps	0.0 Amps	0.0 Amps	25.0 Amps
Future Group 2 Equipment	0.0 Amps	36.0 Amps	36.0 Amps	0.0 Amps
Total AC Load on New UPS	79.8 Amps	55.0 Amps	76.0 Amps	58.0 Amps
UPS Power @ 120 VAC (Assume PF = 1.0)	9576 Watts	NA	9120 Watts	NA
UPS Rating (Assume Efficiency = 0.80)	12 KW	NA	12 KW	NA
UPS Remaining Margin	20.2%	NA	24.00%	NA

Table 2 Evaluation Results for New 15 KVA UPS Systems (Revised Configuration)

MAINTENANCE

Adequate maintenance and surveillance testing of UPS systems should be performed on regular intervals, along with the necessary repair or replacement of components and equipment, in order to ensure proper operation when needed. The manufacturer's instruction manual and recommendations should be consulted for detailed maintenance activities but included in this are the following items:

REGULAR MONITORING INDIVIDUAL BATTERY CELLS

This is especially true for lead-acid batteries which must be monitored for electrolyte level, Specific Gravity, Cell Voltage and condition of the cell posts and connectors.

Low electrolyte level will lead to shortened life of the battery cell and low specific gravity is an indication that the cell is not fully charged. Inspection of the connections and cell posts will preclude battery failure as corrosion at the posts is an indication that the cell is leaking. VRLA batteries were once considered as "maintenance free" however it has later been determined that this type of battery cell can be damaged due to overcharging, which can lead to depletion of electrolyte. Because the electrolyte in these batteries cannot be replaced, the individual cell must be replaced when it is determined that its condition is questionable.

REGULAR MONITORING OF INVERTER AND CHARGING SYSTEM

In addition to the condition of the inverter, the charging system for the batteries should be also monitored and proper maintenance steps taken to ensure the system is performing properly. Improper regulation and filtering or malfunction of the battery charger can lead to premature failure of the UPS system batteries. Excessive DC ripple on the charging system output can result in overheating and shortened battery life, which is especially true for VRLA batteries [2].

The charger output voltage should be regularly monitored to ensure that the charger will maintain the battery's charge and that the output voltage is within the battery manufacturer's recommendations. The condition of the UPS rectifier, inverter, static switch and other components should be monitored and any defective parts replaced. All alarms should be verified to be operating properly and adjusted if necessary.

SUMMARY

In this paper we have covered in detail the process involved and deciding factors which should be used in selection of an AC power source for a digital control system, including the need for quality uninterruptible power, types of UPS systems and their configuration. We have also briefly discussed the types of individual components batteries, chargers, rectifiers and inverters and their advantages and disadvantages. Finally we have discussed the need for properly operating charging systems, monitoring and alarm systems along with the minimum maintenance practices that are necessary to ensure their satisfactory performance.

In conclusion, it is recommended that careful consideration be given when installing a digital control system to ensure that the power source(s) used will deliver both the quantity and quality of reliable backup power to ensure reliable performance and ensure that the digital control system will perform it's design function for as long as need in the event of a loss of normal AC power. In addition, the need for proper planning that addresses the load of new systems to be installed and future expansion is critical to ensure their satisfactory performance.

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