C&D TECHNOLOGIES

UPS Applications and VRLA Battery Sizing

The uninterruptable power system (UPS) is used to protect critical equipment and processes from the consequences of an interruption to their commercial power source. Typical of the equipment and processes which require this commercial power protection are computers for data processing, continuous processes such as in refining and automated manufacturing, life support equipment, communications equipment and hazard monitoring and alarm systems.

The UPS System

Typically the UPS has a dual function of conditioning the commercial power, that is to eliminate spikes, frequency swings and minor voltage swings, and to provide temporary power during commercial power outages. It is the battery system that supplies the emergency standby power to the UPS electronics during these outages and determines the reliability of the total system.

The basic functions of the UPS are the same whether of small systems powering only a single personal computer or large units which power complete data processing centers.

As shown in Figure 1 the commercial power is supplied to a charger/rectifier which converts the commercial power from 60 Hertz AC to a pure DC power to charge the standby battery system and power the DC-to-AC inverter. The inverter then converts the DC power, whether from the rectifier or the battery, to AC power usable by the critical load. The UPS magnetics and inverter regulate the output to compensate for brownouts and provide frequency control to eliminate the affect of any commercial power frequency variations. In the event of a commercial power outage, the battery would be the primary power source to the inverter to assure uninterrupted output for a limited time to the critical load.

The size of the battery determines how long the inverter will continued to provide power to the critical load. With small UPS systems such as might power an individual personal computer, the battery may supply from 10 minutes to 3 hours of standby operating time. However, with large UPS systems as would be used to power a complete data processing center, a battery would typically be sized to provide 10 to 30 minutes. This is just enough time to provide an orderly shutdown of the process or allow for continued operation while a separate diesel generator is started to provide long term standby power.

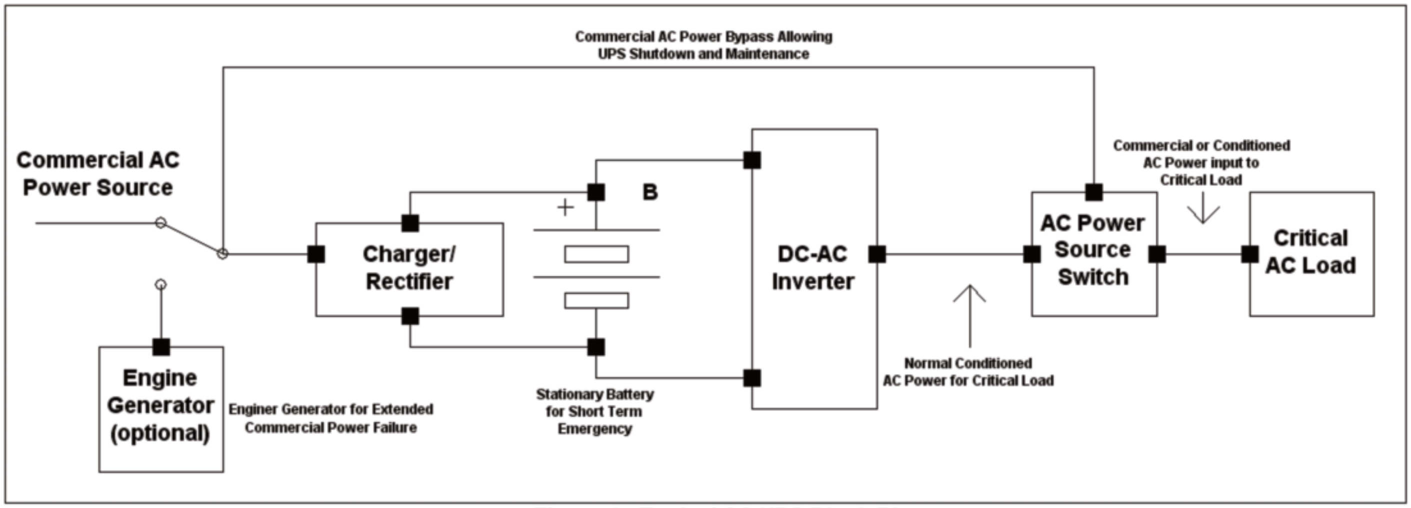


Figure 1 - Typical AC UPS Block Diagram

UPS System Ratings

The UPS systems are typically rated in terms of their volt-ampere output at a specific power factor. For example, a UPS for a personal computer might be capable of supplying 120 VAC at 4 amperes with a power factor of 0.8. This system would be rated at 480 volt-amperes (120 VAC x 4 amperes = 480 volt-amperes) at a 0.8 power factor. The AC output wattage capability is simply the volt-ampere rating times the power factor or:

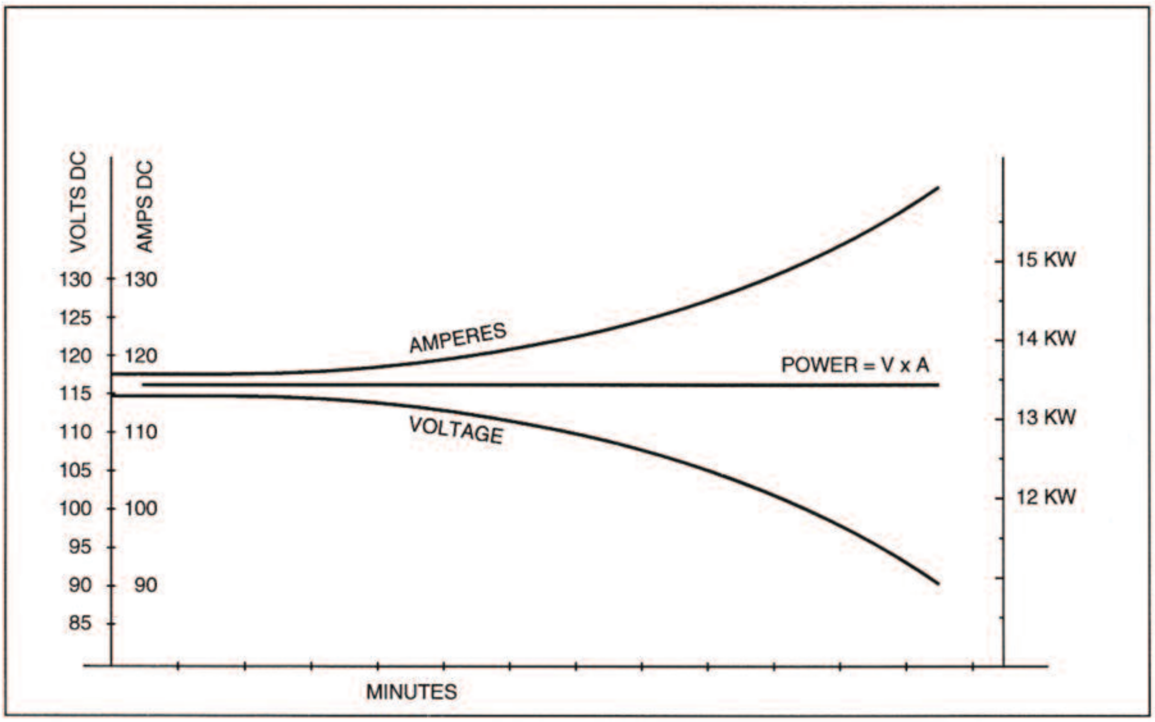
watts = volts x amperes x power factor

384 watts = 480 volt-amperes x 0.8 power factor

The larger UPS systems are normally rated in thousands of volt-amperes (kilo volt-amperes or KVA) at a specific power factor. For example, a UPS capable of delivering 125 amperes at 120 volts at a power factor of 0.8 would be rated at 15 KVA (125 amperes x 120 volts) at 0.8 power factor. In terms of wattage this would be 12 KW (15 kilo volt-amperes x 0.8 power factor = 12 kilowatts). This is also the power that must be supplied to the inverter, plus losses due to inefficiencies, by the battery during standby operation.

UPS Battery Load and Battery Ratings

The UPS inverter supplies a constant power (constant wattage) to the critical load. Consequently it places a constant power (voltage x current) load on the battery. For example, as shown in Figure 2, if the battery load were initially 114 VDC and 117 amperes (114 VDC x 117 amperes = 13.34 KW) the load would be 133.4 amperes when the battery voltage declined to 100 VDC (133.4 amperes x 100 VDC = 13.34 KW) during discharge.



Constant Power Battery Discharge
Figure 2

The battery is producing power or watts (voltage x amperes) during its discharge. Note that in Figure 3 each of the 6 cells in series are producing 75 amperes at 2 volts or 150 watts (2 VDC x 75 amperes = 150 watts). At 150 watts per cell the 6 cell battery is producing a total of 900 watts or 0.9 kilowatts.

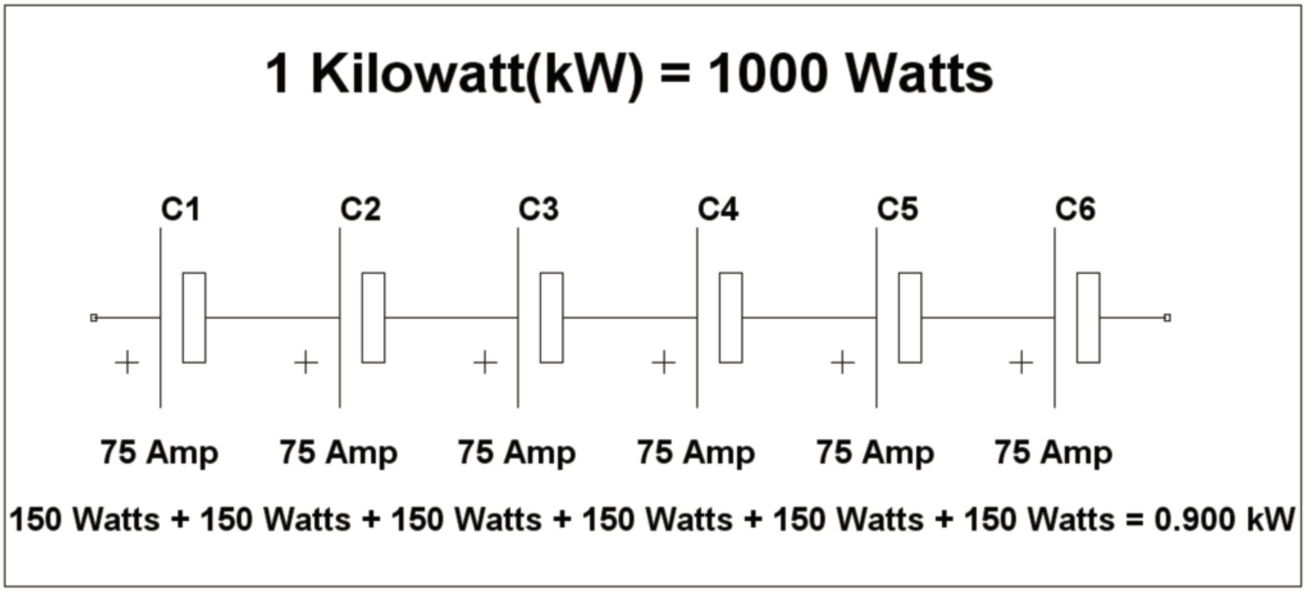


Figure 3 - Wattage Per Series Cell

For convenience in sizing, the batteries are rated in watts per cell for a specified operating time to a specific end point voltage. These rating are at a standard 77°F. For example, Table 1 indicates the capability of various of the UPS series batteries at varied operating times and end point voltages.

The VRLA UPS series battery part numbers also reflect the battery's approximate capability. For example the UPS 12-350MR is a 12 VDC battery of 6 cells which is capable of delivering 348.0 watts of power per cell for 15 minutes to 1.67 volts per cell.

Table 1-UPS

Part Number	End Voltage Per Cell	Watts Per Cell Discharge Time in Minutes										
		5	10	15	20	25	30	40	45	50	60	90
UPS12-100MR	1.75	157.1	114.2	87.5	72.1	62.1	54.9	45.0	41.5	38.5	33.7	24.8
UPS12-150MR	1.75	272.9	182.1	139.9	114.8	98.0	85.7	68.8	62.7	57.6	49.7	35.0
UPS12-210MR	1.75	340.7	242.5	193.3	161.8	139.4	122.6	99.0	90.3	83.0	71.5	50.6
UPS12-300MR	1.75	493.4	359.9	281.3	232.4	199.0	174.6	141.0	128.9	118.7	102.8	73.5
UPS12-350MR	1.75	534.3	409.6	327.2	272.2	233.3	204.5	164.5	150.0	137.9	118.9	84.3
UPS12-400MR	1.75	611.9	470.0	374.0	309.8	264.8	231.5	185.6	169.1	155.3	133.7	94.7
UPS12-490MR	1.75	655.2	527.3	442.6	381.9	336.0	300.0	247.3	227.3	210.3	183.0	131.8
UPS12-490MRLP	1.75	633.2	541.1	455.6	385.0	330.8	289.5	232.3	211.8	194.9	168.3	120.7
UPS12-540MR	1.75	728.2	564.4	471.2	406.0	356.8	318.2	261.1	239.4	221.0	191.2	135.7
UPS12-615MRF	1.75	787.0	677.0	573.0	486.0	417.0	369.0	300.0	275.0	254.0	221.0	161.0
UPS6-620MR	1.75	861.6	681.0	573.2	496.6	438.1	391.8	322.9	296.5	274.0	237.4	169.2
UPS12-700MRF	1.75	821.1	700.8	596.0	512.5	448.1	398.3	326.9	300.6	278.5	243.2	177.7
UPS12-100MR	1.67	171.7	117.0	90.9	75.4	64.9	57.2	46.5	42.6	39.3	34.1	24.6
UPS12-150MR	1.67	290.3	192.7	147.0	120.1	102.0	88.9	71.1	64.7	59.4	51.1	36.1
UPS12-210MR	1.67	373.4	260.5	203.8	168.7	144.4	126.5	101.6	92.6	85.1	73.3	51.9
UPS12-300MR	1.67	546.0	385.3	298.4	245.3	209.2	182.8	146.7	133.6	122.8	105.8	75.0
UPS12-350MR	1.67	618.8	439.9	348.0	289.0	247.3	216.1	172.6	156.8	143.7	123.0	85.9
UPS12-400MR	1.67	716.3	506.3	397.4	328.3	280.1	244.4	195.0	177.1	162.3	139.0	97.2
UPS12-475MRLP	1.67	779.8	589.7	474.8	387.9	329.6	287.5	230.3	209.8	192.8	166.2	118.1
UPS12-490MR	1.67	770.9	592.9	484.6	411.1	357.5	316.7	258.2	236.6	218.3	189.1	135.3
UPS12-490MRLP	1.67	772.4	607.2	486.0	402.4	343.3	299.8	240.0	218.5	200.6	172.7	122.3
UPS12-540MR	1.67	874.5	657.2	534.3	451.0	390.0	343.3	276.6	251.9	231.2	198.4	138.8
UPS12-615MRF	1.67	938.5	750.9	613.9	515.9	444.1	389.8	313.4	285.5	262.3	225.7	
UPS6-620MR	1.67	937.6	746.6	620.0	529.9	462.6	410.4	334.8	306.6	282.7	244.6	174.1
UPS12-700MRF	1.67	1,058.80	853.6	690.9	575.3	493.1	432.5	349.0	319.0	294.0	254.6	182.9
UPS12-100MR	1.65	173.7	117.9	91.5	75.9	65.3	57.6	46.9	42.9	39.7	34.5	24.8
UPS12-150MR	1.65	293.9	196.3	149.3	121.7	103.3	90.0	71.8	65.3	60.0	51.5	36.4
UPS12-210MR	1.65	378.3	262.1	205.2	169.9	145.5	127.5	102.4	93.3	85.7	73.8	52.1
UPS12-300MR	1.65	564.1	395.4	301.9	246.6	209.8	183.4	147.4	134.4	123.7	106.9	76.2
UPS12-350MR	1.65	637.6	455.3	358.1	295.8	252.1	219.8	174.9	158.7	145.2	124.2	86.5
UPS12-400MR	1.65	739.8	515.1	402.8	332.3	283.3	247.1	197.0	178.9	163.9	140.3	98.1
UPS12-490MR	1.65	798.8	614.0	497.4	419.0	362.9	320.6	260.8	238.8	220.3	190.9	136.9
UPS12-490MRLP	1.65	802.8	630.9	500.3	410.8	348.6	303.4	242.0	220.1	202.0	173.8	123.1
UPS12-540MR	1.65	912.3	683.1	550.4	461.6	397.5	349.0	280.4	255.2	234.2	201.0	140.9
UPS12-615MRF	1.65	959.0	772.0	628.0	525.0	450.0	394.0	316.0	287.0	264.0	227.0	170.0
UPS6-620MR	1.65	951.0	763.4	634.2	541.6	472.3	418.8	341.5	312.7	288.3	249.6	178.0
UPS12-700MRF	1.65	1075.6	866.0	699.2	581.1	497.6	436.1	351.8	321.5	296.3	256.7	184.5

Selecting the UPS Battery

Usually the UPS battery load is provided in terms of kilowatts (KW_B) along with the inverter nominal DC bus voltage, the inverter minimum operating voltage and the required operating time.

From this information must be calculated the number of cells, required watts per cell and the end point voltage per cell so that the proper cell can be selected from tables similar to Table 1.

For example a UPS rated at 250 VA for an individual PC may utilize a 12 VDC bus to the inverter which can continue operation at a minimum input voltage of 10.5 VDC. Assume the load on the battery is 300 watts and the required standby operation is 45 minutes. The number of cells would be calculated as:

$$\text{Number of Cells} = \frac{\text{Inverter Nominal DC bus voltage}}{\text{Number of Cells}} \qquad 6 \text{ cells} = \frac{12 \text{ VDC}}{2 \text{ V/C}}$$

The watts per cell would be calculated as:

$$\text{Watts per Cell} = \frac{\text{Inverter Load on Battery } (W_B)}{\text{Number of Cells}}$$

$$50 \text{ Watts per Cell} = \frac{300 \text{ Watts } (W_B)}{6 \text{ Cells}}$$

The end point voltage cell would be calculated as:

$$\text{End Point V/C} = \frac{\text{Inverter Minimum Operating Voltage}}{\text{Number of Cells}}$$

$$1.75 \text{ V/C} = \frac{10.5 \text{ VDC}}{6 \text{ Cells}}$$

The battery to be selected must be capable of 50 watts per cell for 45 minutes to an end point voltage per cell of 1.75 VDC. In this case the battery to be selected is shown in Table 1 as the UPS12-150 which is actually capable of 68.8 watts per cell for 45 minutes.

A larger UPS rated at 60 KVA might use a 360 VDC battery and require 53 KW of battery power (KW_B) for 15 minutes of standby operation to a minimum inverter operating voltage of 300 VDC.

In this case 180 cells (360 VDC/2 V/C) would be required.

The required watts per cell is:

53 KW/180 Cells = 0.29 KW/cell or 290 watts per cell

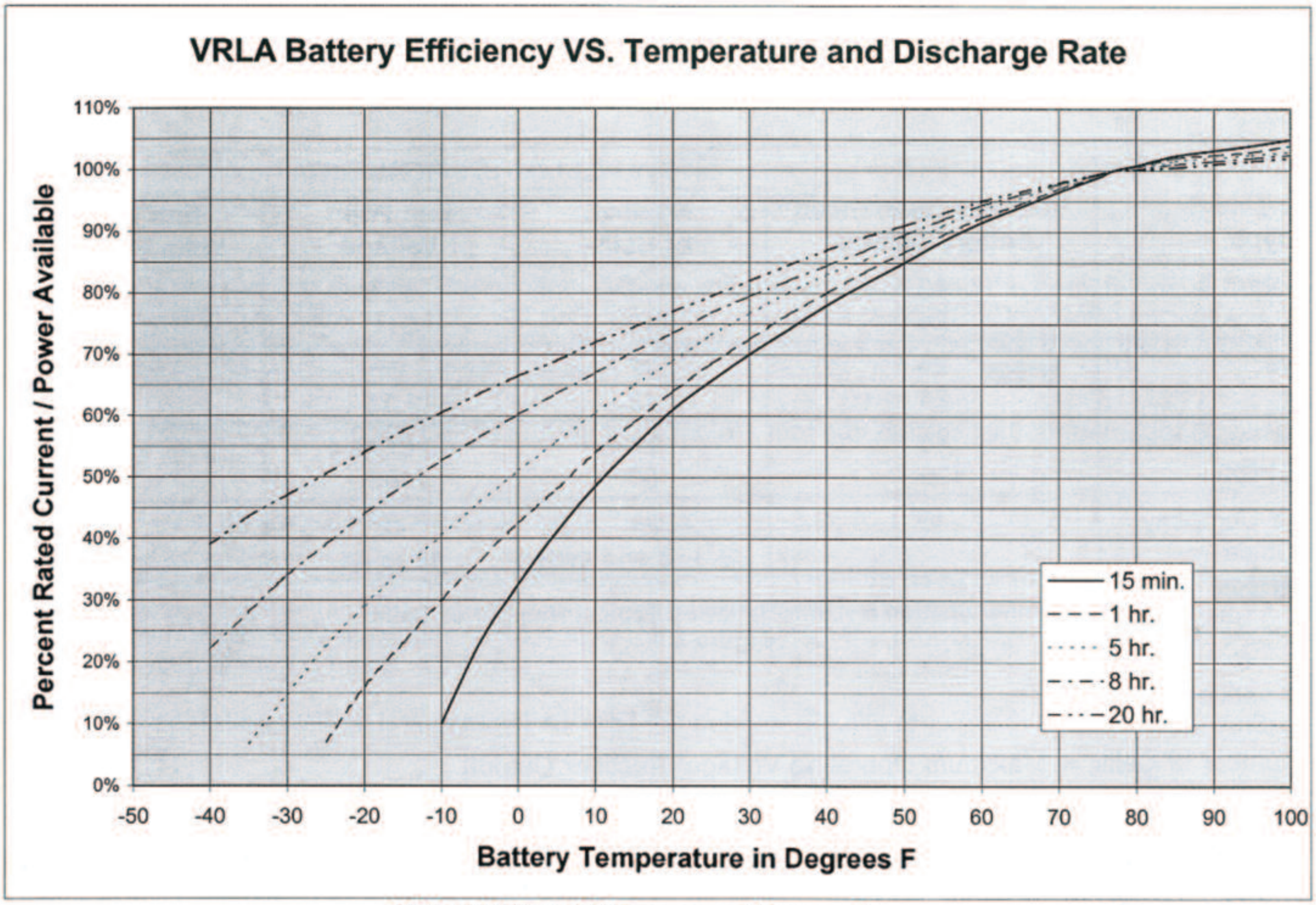
The minimum voltage per cell is:

300 VDC/180 Cells = 1.67 V/C

The required battery would be selected from Table 1 as the UPS12-300MR which can deliver 298.4 watts per cell for 15 minutes to a minimum voltage of 1.67 volts per cell. Since a 180 cell system is required and the UPS12-300MR has 6 cells, 30 of the units would be required in a series connection.

Battery Performance and Temperature

The batteries are rated in watts per cell to an end voltage at 77°F. Cooler operating times will reduce the actual operating time while warmer temperatures will extend it. The performance of the battery for different discharge times vs. its operating temperature is illustrated in Figure 4. Note that the greater the discharge rate (shorter discharge time) the greater will be the degrading effect of cooler temperatures. At 77°F, 100% of the rating is obtained at the 15 minute rate, while only 96% and 91% capacity is attained at 70° and 60°F respectively.



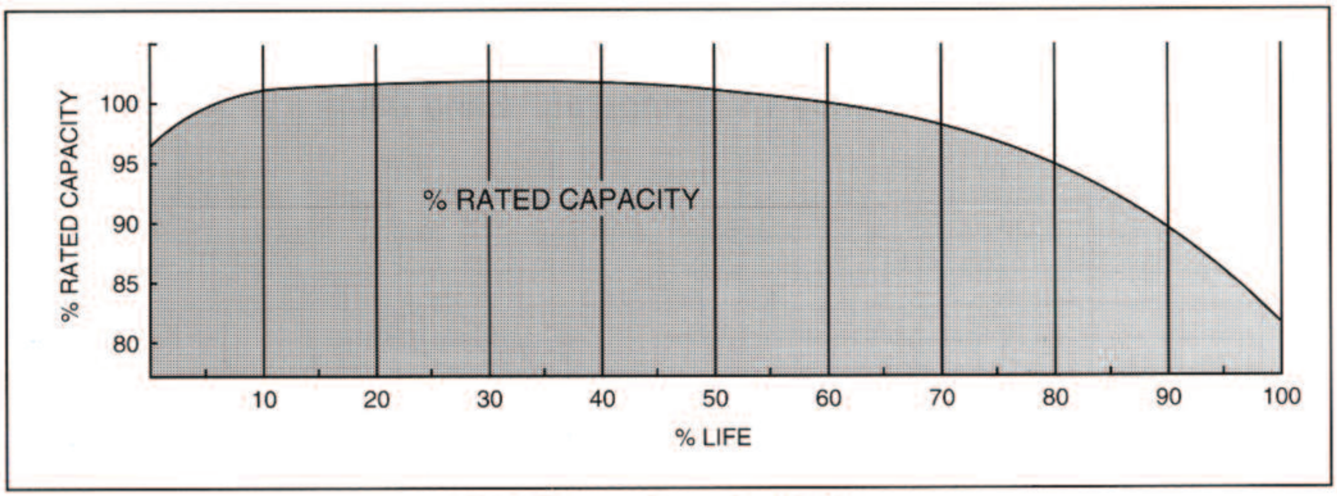
VRLA Battery Efficiency vs. Temperature
Figure 4

When the operating temperature is expected to be lower than 77°F and the specified operating time is required at the lower temperature, it is required that a larger battery be selected to compensate for the degraded performance.

In the previous example, 290 watts per cell were required for 15 minutes. If the operating time were required at 60°F the battery would need to be sized to be able to deliver 290 watts per cell when only 91% efficient. The battery required would have to be able to provide 318 watts (290 x 1/0.91) at 77°F when 100% efficient. In this case the UPS12-300MR would not be capable of delivering the required power for 15 minutes and a UPS12-350MR would be selected. Note that in Table 1 the UPS12-350MR would actually provide approximately 21 minutes operation at 77°F.

Battery Age and Performance

Typically the VRLA battery will grow in capacity during its first 5% of service life and then will plateau at 100% of fully developed capacity through 70% of its life. The battery will then start to decline in capacity until 80% of its rating is reached which is defined as the end of its useful life. This is shown in Figure 5.



VRLA Battery Capacity VS Life
Figure 5

Naturally, if the battery must deliver the 15 minutes of performance when at its end of life of 80% of rating, it will have to be of proportionately greater capacity when new to accommodate the loss in capacity during its normal life.

In the preceding example, 318 watts per cell battery was required to provide the 15 minutes at 60°F when the battery was new. However, if the 15 minutes are still required at the battery end of life the "when new" requirement would be 25% greater or 398 watts per cell (318 watts per cell x 1/0.8). As noted in Table 1, this would require a UPS12-490MR which can deliver the 290 watt/cell requirement for between 30 and 40 minutes (approximately 33 minutes) when new at 77°F.

Calculating the Battery Kilowatt Load (KW_B)

Occasionally the load placed on the battery is not given and must be calculated. The battery must be capable of supplying the inverter output kilowatts plus the inverter losses. All that is required to calculate the KW_B is the UPS rated KVA output and power factor and the inverter efficiency.

The battery load (KW_B) is then calculated as:

$$KW_B = \frac{\text{UPS KVA x Power Factor}}{\text{Inverter Efficacy}}$$

For example, if a UPS were rated at 100 KVA output at 0.8 power factor and had a DC-to-AC conversion efficiency of 93%, the KW_B is calculated as:

$$86.02\ KW_B = \frac{100\ KVA \times 0.8}{0.93}$$

Calculating the Maximum and Minimum Number of Cells

There will be times when the specific number of cells to be used is not provided and is left to the discretion of the person doing the sizing. When this is the case it is necessary to know the operating voltage window of the UPS inverter. That is, the maximum voltage the rectifier/charger can supply for equalizing the battery and at which the inverter can operate and the minimum voltage at which the inverter will continue to function.

Maximum Number of Cells

The maximum number of cells is calculated as the maximum output voltage available from the charger to the inverter divided by the recommended equalization voltage per cell:

$$\text{Max. No. Cells} = \frac{\text{Max. Rectifier Output Voltage}}{\text{Recommended Equalization V/C}}$$

For example, if the upper end of the voltage window were 260 VDC on equalize and the recommended equalization voltage per cell shown in the battery data sheet was 2.4 V/C, the maximum number of cells would be calculated as:

$$191.7\ \text{cells maximum} = \frac{260\ \text{VDC}}{2.4\ \text{V/C}}$$

Minimum Number of Cells

The minimum number of cells is the inverter minimum operating voltage divided by the preferred end point voltage per cell for the given discharge time.

$$\text{Minimum No. Cells} = \frac{\text{Inverter Minimum Operating Voltage}}{\text{Recommended End Point Voltage per Cell}}$$

For example, if the UPS above were to perform on battery for 15 minutes to an end point of 299 VDC and a typical end point voltage per cell of 1.67 were selected, the minimum number of cells would be calculated as:

$$179.0\ \text{cells minimum} = \frac{299\ \text{VDC}}{1.67\ \text{V/C}}$$

Optimum Number of Cells

In this case the optimum number of cells would be between 179 and 192 cells. Usually the number of cells selected will be a multiple of 6 or 3 since the available C&D batteries have 6 or 3 cells per unit (e.g., UPS12-310 and UPS6-620 respectively). In this situation, 180 cells would be initially selected and the battery sizing problem completed.

If in completing the problem it was found that the required watts per cell were slightly greater than available from a preferred part number, an additional 6 or 3 cells, as appropriate, could be added to the string and the new watts per cell required and new end point voltage calculated. It may be that the addition of these cells would result in not having to use a higher capacity part number battery and a more economical system would result.

Operation of Parallel Battery Strings

When the required watts per cell is calculated and found to exceed the capability of an individual cell, parallel operation may be considered.

For example, assume previous calculations indicated a requirement for 1.2 KW per cell, with 180 cells being discharged to 1.67 V/C for 15 minutes. The largest available cell is the UPS 12-615MRF capable of 0.614 KW per cell. However, two strings could be operated in parallel as shown in Figure 6 to produce 1.240 KW per cell which more than meets the requirement.

Normally, for the UPS battery systems of 120 and more cells no more than four parallel strings are recommended. This is due to the practical considerations of the number of bolted connections to be made and maintenance requirements. Although a higher number of parallel strings can be done safely, extra precautions must be taken to ensure the strings are properly balanced.

The following guidelines should be followed when operating parallel strings of batteries:

1. Batteries should all be of the same model number
2. Each string should be connected to an individual disconnect or circuit breaker
3. Cabling to each string should be of the same size and approximate length resulting in the same resistance per string.
4. The size of cable selected should consider the NEC code, allowable voltage drop and maximum load current expected per string.
5. All parallel strings should be joined in parallel at a separate "J" box or the UPS
6. If, through either planned or unplanned string disconnection, a fewer number of strings may feed the UPS during an outage, the batteries, cables and all other components in the circuit must be sized for the maximum anticipated current.

Disconnect Switches

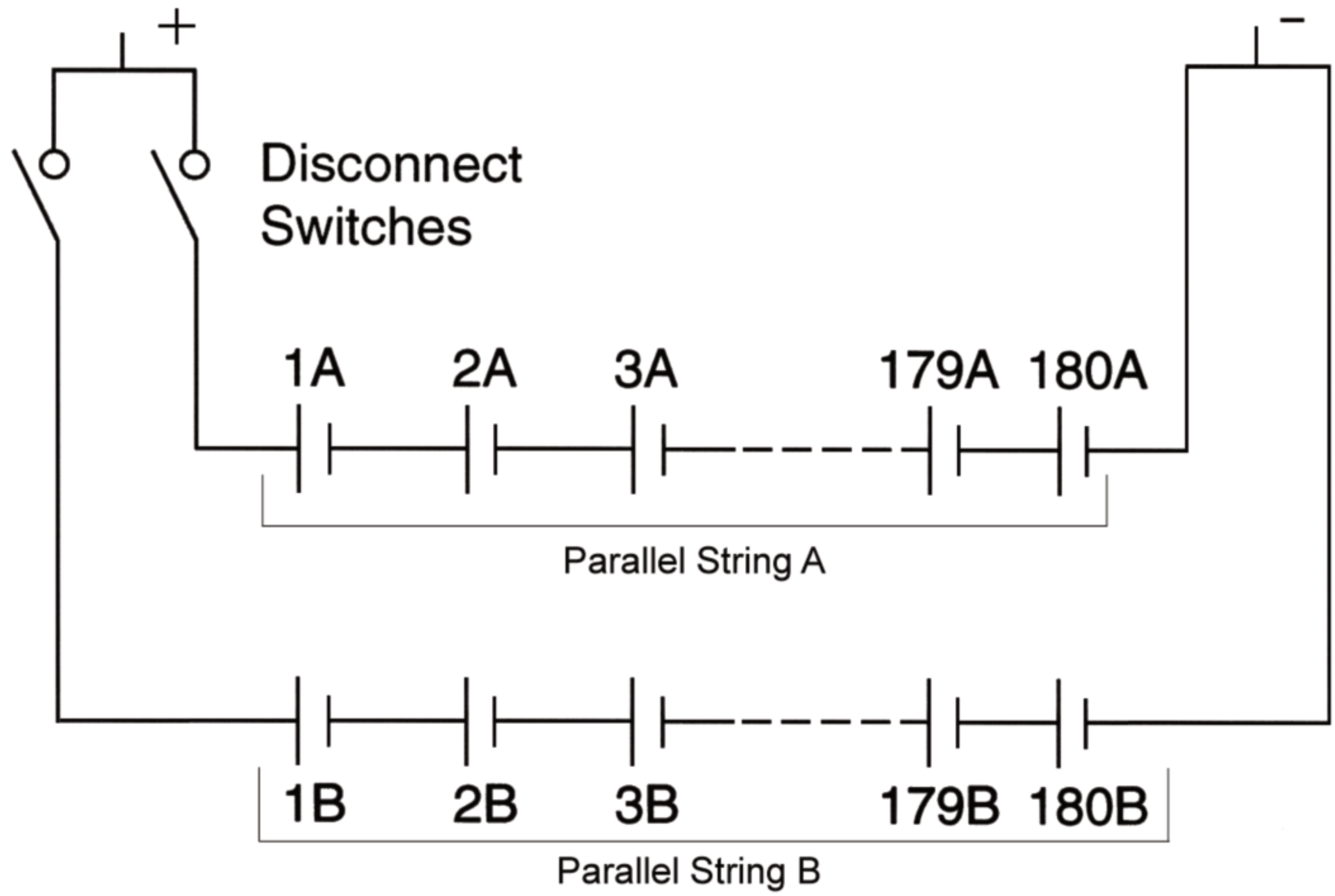


Figure 6 - Parallel Operation of Battery Strings

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