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Technical Reference

Battery Performance

Introduction

This document presents information on Capstone Model C30 and Model C60 battery life expectancy and battery performance in Stand Alone applications. The battery has an integral function in all aspects of MicroTurbine operation from start-up to shut down, as well as DC bus support.

In Stand Alone operation, the primary functions of the battery are:

- Provide power during onload transients
- Accept power during offload transients
- Provide power while starting and stopping the MicroTurbine
- Provide power during standby state.

Battery life expectancy is dependent on several factors including operating and storage temperature, the number of charge and discharge cycles, number of transients (and their interval), and internal/external loads such as fuel compressors. These life factors will be examined as they relate to Model C30/C60 configurations in the sections that follow.

Battery performance is tied to regularly scheduled maintenance and equalization charging to optimize battery life and ensure that the battery performs as designed. Refer to the Capstone Standard Maintenance Schedule Work Instruction (440000) for information on regular maintenance schedule intervals. Refer to the Stand Alone Operation Technical Reference (410028) for instructions on battery pack equalization charging.

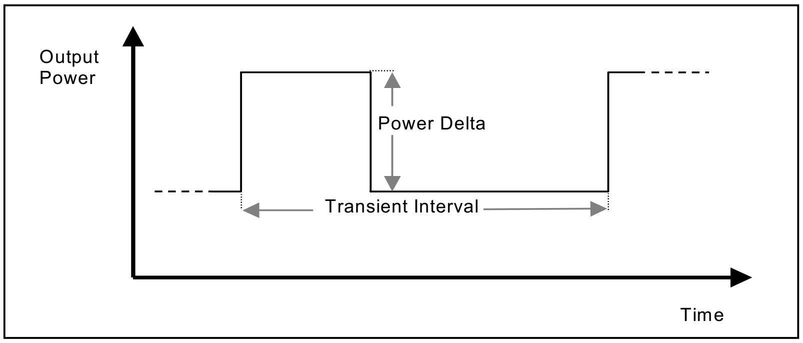
Figure 1. MicroTurbine Battery (Model C60 shown)

Definitions

Power Derating is the decrease in nominal net output power for the system and is equal to the rate of power drain from the battery.

For example: if the battery is being drained at a rate of 1kW, then the MicroTurbine will require 1kW of power to recharge it. This power will not be available for the load.

Transient Interval is the time between the start of successive transients.



Transient Size (or Power Delta) is the total change in load for the transient.

Battery Use in Stand Alone Systems

Battery performance varies between C30/C60 high pressure and C30 low pressure (and liquid fuel) systems as described in the paragraphs below.

Model C30 (and C60) High Pressure System

The most demanding period of operation for the battery is when the MicroTurbine is changing from one power level to another. During positive step loads (increase in power level) the generator must increase speed to provide more power to the load. During this step, the battery provides power to assist the engine increase in speed, as well as supplying power for the load via the BCT (C30) or BCM (C60). During negative step loads (decrease in power level) the generator must decrease the speed to provide less power to the load. Excess energy from the engine is sent to the battery pack (and brake resistor if necessary).

Model C30 Low Pressure and Liquid Fuel System

Low pressure and liquid fuel system battery usage is equivalent in most respects to the high pressure system. The fuel compressor requires additional power during transients and therefore adds additional load to the battery. The amount of additional load is not significant for small transients but is significant for larger transients.

Life Estimation for Cyclic Applications

The estimation of battery life in a Stand Alone application is complicated and depends on many factors. Battery life is affected directly by the number of charge and discharge cycles that occur. During step loads, the battery loses a certain amount of charge depending on the size of the step load. After some number of transients, the battery SOC reaches a minimum limit and the battery is recharged. Each recharge cycle will degrade the life of the battery to some extent.

Several assumptions are made for these calculations: 1) there are no defective cells within the battery, and 2) there is no significant portion of downtime for the system when the battery is held at a low state of charge. Long periods of storage when the battery is not charged, and over discharged can permanently harm the battery, and significantly reduce life.

Battery Life in Other Applications

Many applications require a battery for backup Stand Alone use only. Long periods of standby do not harm the battery, as long as its charge is maintained. Normal aging of the battery will cause some degradation, and replacement will eventually be required.

Dual Mode and ATS Applications

In Dual Mode and ATS (Automatic Transfer Switch) applications, the MicroTurbine runs primarily in a Grid Connect mode or does not run at all. In both scenarios, the battery is not used for extended periods of time. The majority of the battery degradation will be due to ambient temperature and time. It is estimated that most systems in this configuration will run in Stand Alone mode for eight (8) hours or less each year. For this reason, degradation due to battery cycling during Stand Alone operation can be ignored.

C30 ATS Applications

For optimum use of the battery, it is not recommended that the C30 system be used in ATS or standby emergency generator configurations, where the engine is not operating a large portion of the time. When grid power is not available the battery can never be recharged fully, since the engine consumes a large amount of energy during cool down. This will significantly reduce the life of the battery, although the exact amount is not known.

C60 ATS Applications

C60 systems that are connected to the grid with an ATS will behave in a slightly different manner. Periodically the engine must be started to charge the battery. This can be set up to occur at some interval and it is recommended that the same intervals as specified in the Standard Maintenance Schedule Work Instructions (440000). When the engine stops, it consumes some energy from the battery. The battery is never left in a 100% SOC condition. This will degrade the battery life slightly; a rough estimate would be 10% to 20% of the battery life is lost due to this. In addition, the engine run time can vary between a full equalization charge of four (4) hours and a short recharge time of 30 minutes. The shorter recharge time may not recharge the battery completely, and may degrade the battery somewhat. It is estimated that this will contribute another 10 to 20% loss of life. When calculating life for ATS, or standby applications adjust the life estimate accordingly.

Calculation of Battery Life Expectancy

How the Calculator Works

To obtain an estimate for battery life, the Expected Cycle Life hours should be multiplied by three factors; Temperature Derating, Starts Derating and End of Life Rating. Each of these values is determined from the appropriate chart. This will give an estimate of battery life in Stand Alone operating hours.

The basic format for this calculation is:

Expected life = Cycle Life * Temperature Derating * Starts Derating * End of Life Derating

What you will need to know: this data is required before a life estimate can be calculated.

- System type
- Transient Size in Watts
- Transient interval in seconds
- Ambient temperature in \C
- Number of starts in 1 year
- Maximum transient required for the application

Step 1: Find the appropriate *Expected Cycle Life* Chart for the System.

High and low pressure systems require different amounts of energy for transients, so find the appropriate chart to obtain data in Figure 2 “Expected Cycle Life”.

Step 2: Find the *Number of Operating Hours* using Transient Size and Transient Interval.

Using Figure 2 “Expected Cycle Life”, the size of transient required is found on the y-axis. The value of the transient interval is found on the x-axis. Where these points intersect, the number of operating hours can be read from the chart. If the point lays between two lines then the number of operating hours from the left most line should be used (the lowest number). The maximum that should be used for any calculation is 26280 hours. Use 5 years (43800 hours) for standby, dual mode or emergency generator applications.

Step 3: Find the *Operating Temperature of the Battery*.

Using Figures 3 and 4 “Battery Temperature Increase”, find the temperature increase over ambient. Find the appropriate line for the Transient Size, and the Transient Interval on the x-axis. The Temperature increase over ambient can be read from the y-axis on the chart. Add this value to the ambient temperature to get the battery temperature during operation.

Step 4: Find the *Temperature Derating of the Battery*.

Using Figure 5 “Temperature Derating for Battery Life”, find the battery temperature on the x-axis and read the derating from the y-axis. This number is multiplied by the number of hours from Step 2.

Step 5: Find the *Number of Starts* Derating.

Approximate the number of starts that the MicroTurbine will have in a one-year period. Find this number on the x-axis on Figure 6 “Derating for Number of Starts” and read the corresponding value from the y-axis. This number is multiplied by the number of hours in Step 2. Number of Starts Derating is eliminated from the calculation for standby applications.

Step 6: Find the *End of Life* Derating

The end of the battery life is determined by the maximum transient it will have to perform successfully. This may not be the same transient that is used for the cyclic calculations. This maximum transient will usually occur after startup, and may be similar to the maximum loading of the MicroTurbine in a given application. Find the Maximum Power delta, or Transient size in Watts on the x-axis on Figure 7 “End of Life Factor” and read the corresponding factor from the y-axis. This number will be multiplied by the number of hours (or years) in Step 2. See Figure 7 also for standby applications.

Step 7: Calculate *Lifetime of Battery*.

Multiply the number of hours from Step 2 by the factors from Step 4,5 and 6. The result is the number of operating hours or standby years expected before battery failure.

Examples of Battery Life Calculation

In examples 1 and 2, a Model C30 high pressure Stand Alone system runs daily with a 15 kW base load and 5kW transients every 10 minutes. In Example 3, a Model C60 high pressure Stand Alone system runs as a standby generator.

Data used for the three battery life calculation examples on the following page is presented as follows:

Parameter	Example 1	Example 2	Example 3
System Type	C30 HP	C30 HP	C60 HP
Transient Size (Watts)	5000 Watts	5000 Watts	
Transient Interval (sec)	600 seconds	600 seconds	
Ambient Temperature (\C)	Average (day) = 22\C	Average (day) = 29\C	Average (day) = 35\C
Number of Starts in 1 year	200	200	
Maximum Transient (Watts)	15000	15000	45000

The steps to finding battery life and the results for the examples listed below.

Step	Example 1	Example 2	Example 3
Step 1: Find the appropriate Expected Cycle Life Chart for the system using Figure 2.	C30 HP, 13Ahr	C30 HP, 13Ahr	-
Step 2: Find the number of operating hours using transient size and transient interval.	17520 operating hours.	17520 operating hours	43800 non-operating hours (5 years)
Step 3: Find the operating temperature of the battery using Figure 3.	Temperature increase of 10∀C, operating temperature = 22 + 10 = 32\C	Temperature increase of 10\C from Figure 3, operating temperature = 29 + 10 = 39\C	Temperature = 35\C
Step 4: Find the Temperature derating for the battery using Figure 5.	Derating of 0.65	Derating of 0.36	Derating of 0.50
Step 5: Find the Number of Starts derating using Figure 6.	Derating of 0.98	Derating of 0.98	-
Step 6: Find the End of life derating factor using Figure 7.	Derating of 1.6	Derating of 1.6	Derating of 1.1
Step 7: Calculate the lifetime of the battery.	Expected Cycle Life: 17520 hours Temperature derating: 0.65 Starts Derating: 0.98 End of Life Derating: 1.6 Expected Life = 17520 * 0.65 * 0.98 * 1.6 = 17856 hours.	Expected Cycle Life: 17520 hours Temperature derating: 0.65 Starts Derating: 0.98 End of Life Derating: 1.6 Expected Life = 17520 * 0.36 * 0.98 * 1.6 = 9889 hours.	Multiply 5 years by both factors: 5 years * 0.50 * 1.1 = 2.75 years

Expected Cycle Life Charts

Figure 2 shows the expected battery life (in hours) for a given transient size and interval.

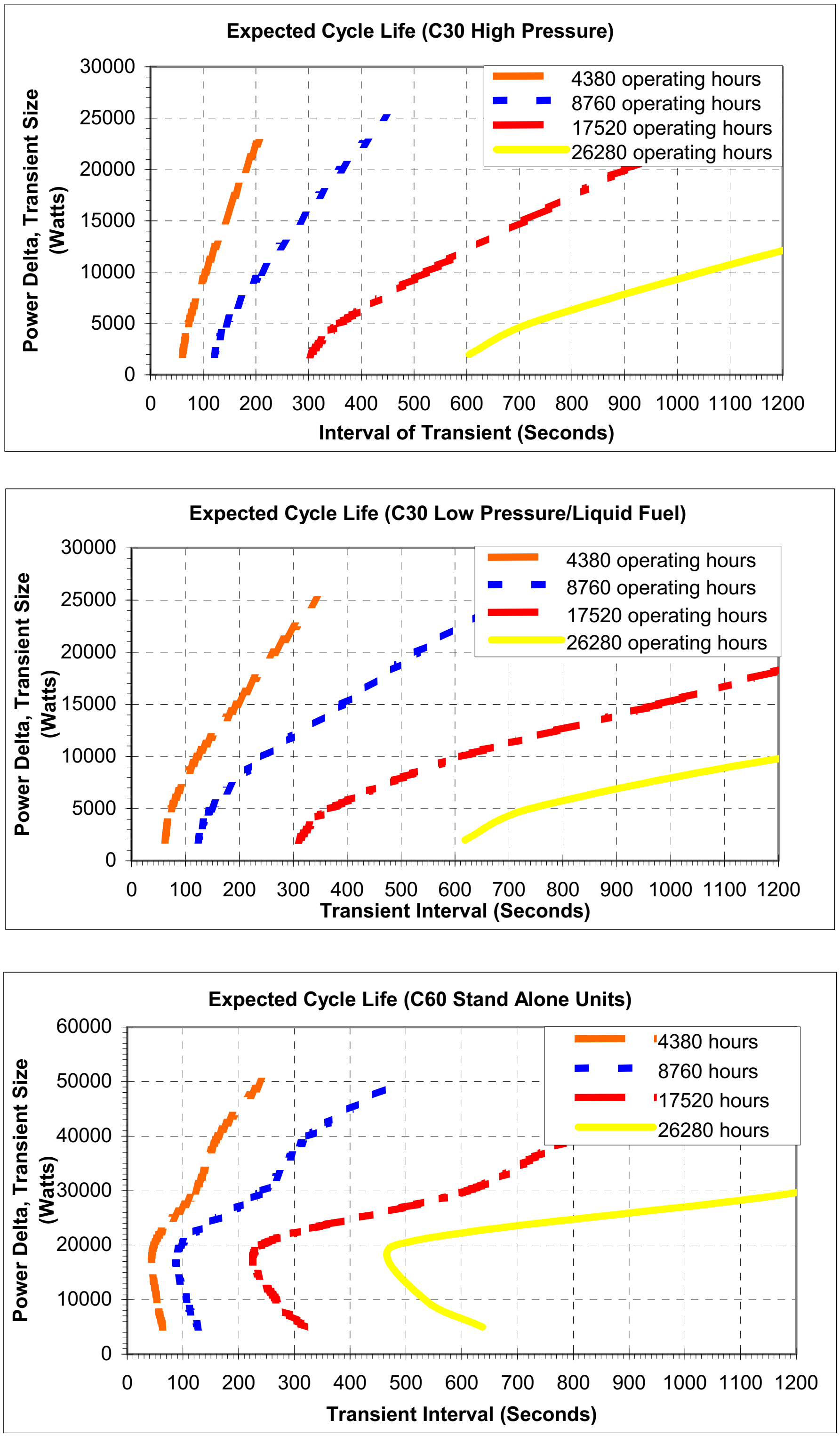
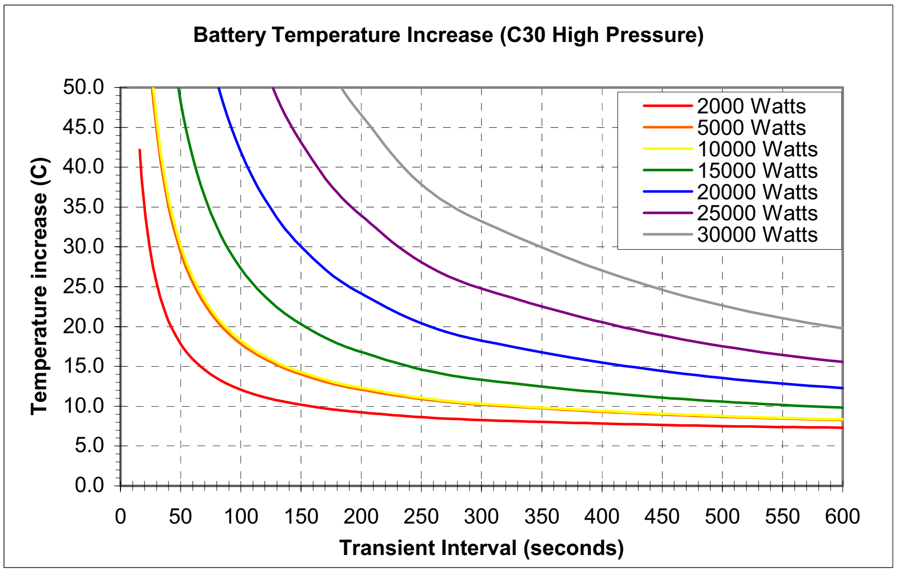


Figure 2. Expected Cycle Life (Models C30 and C60)

Model C30 Thermal Limits during Cycling

The battery pack thermistor measures the external temperature of the battery. This temperature is limited to 65° C to protect the battery case from softening and possible failure. This temperature limit can be reached if the battery is used heavily for some period of time. The limit is a relationship between the current and the thermal properties of the battery.

Figure 3 charts the expected increase in battery temperature (y-axis) for a given transient size (lines), and a transient interval (x-axis). The temperature increase should be added to the maximum ambient temperature. This total cannot exceed 65° C or the system will shut down due to a battery over-temperature fault.



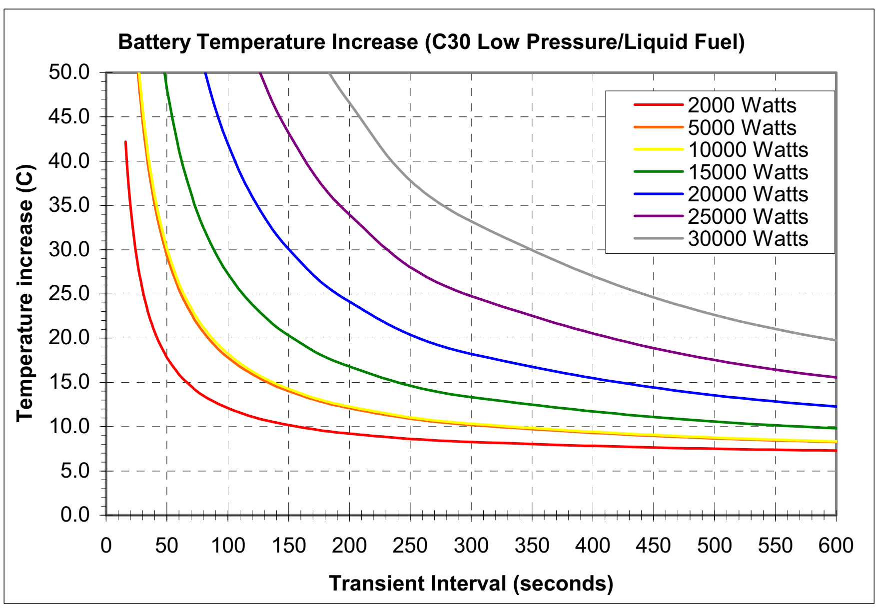


Figure 3. Battery Temperature Increase (Model C30)

Model C60 Thermal Limits during Cycling

All C60 battery packs are equipped with a fan for cooling which results in lower average temperature. The same 65∀C temperature limit applies to the C60 battery.

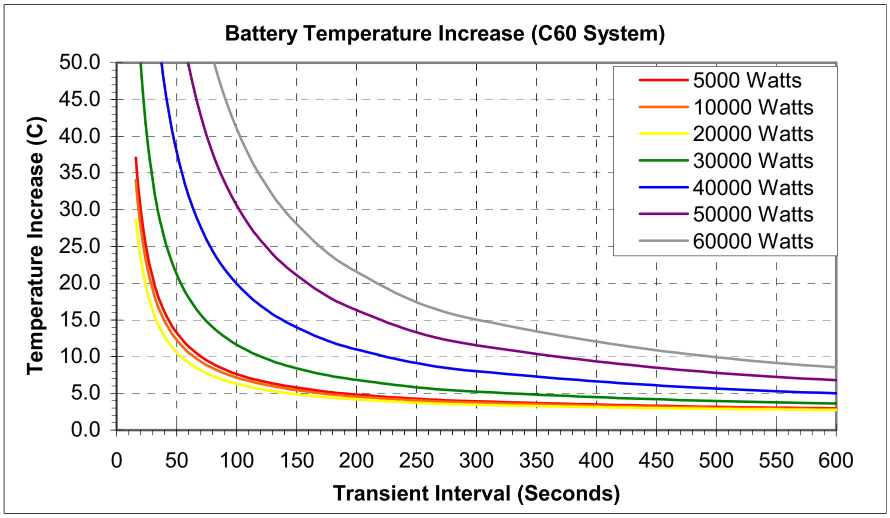


Figure 4. Battery Temperature Increase (Model C60)

Derating for Temperature

Figure 5 shows the appropriate derating factor for a given ambient temperature. The battery temperature during cycling should be estimated by adding the value obtained from the appropriate temperature increase chart, and the ambient temperature.

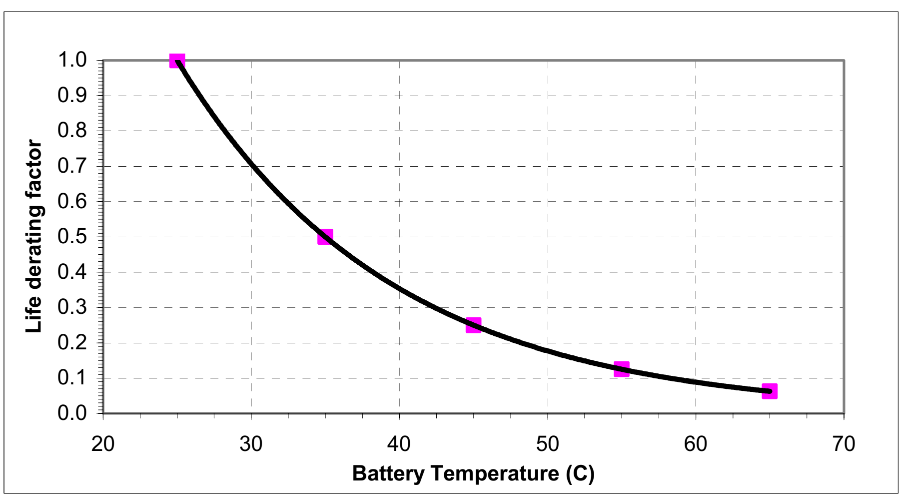


Figure 5. Temperature Derating for Battery Life

Derating for Number of Starts

Figure 6 shows the appropriate derating factor for the number of starts. To find the derating, find the number of starts in one year on the x-axis, and follow the curve up to the line. The derating can be read from the y-axis.

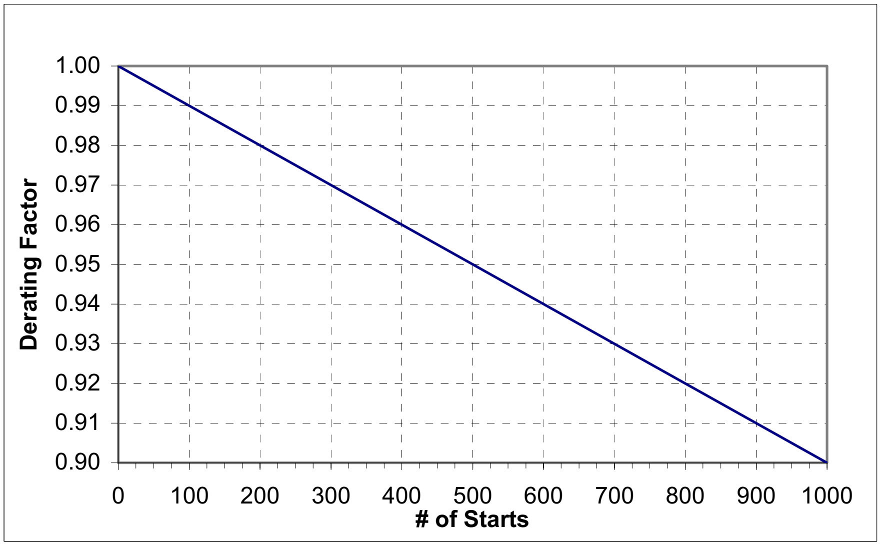
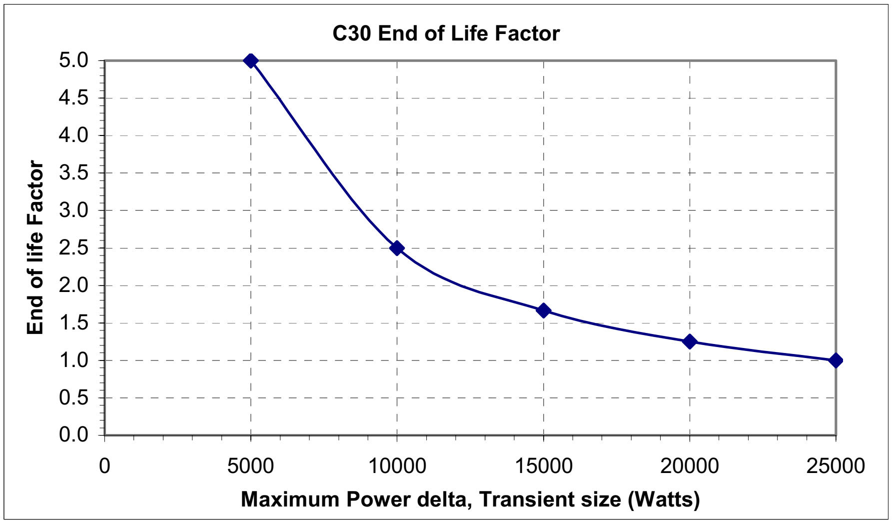


Figure 6. Derating for Number of Starts

End of Life Factor

As the battery ages, the internal resistance grows at some rate depending on usage and temperature. This resistance is the limiting factor for maximum transient operation. Applications with larger transients require a lower internal resistance and will produce battery faults earlier in the battery's life under identical conditions. Applications with smaller transients can tolerate a large internal resistance and will therefore operate longer without producing faults. Figure 7 shows the relative End of Life derating factor based on the internal resistance requirements for each size of transient.



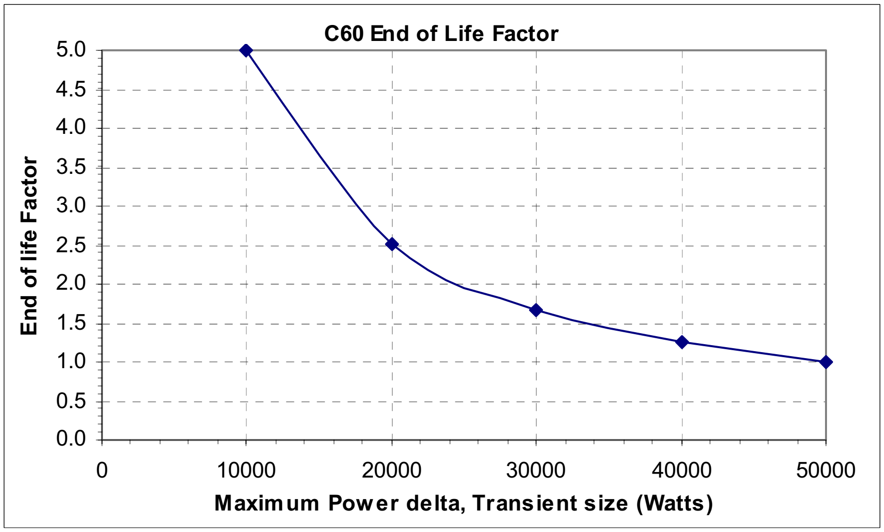


Figure 7. End of Life Factor

Performance Limits

Battery performance is limited by two main factors during cycling. One is the limit at which the battery can recover charge. The charging voltage and current limits are set in the BCT and BCM software, and are a function of battery design. The second limit is the battery temperature. During cycling, the battery increases in temperature from internal resistive losses. The temperature must be limited due to the plastic case of the battery, which will become soft and fail if it reaches a high temperature.

These battery performance limits must be calculated into total system power derating. Refer to the Model C30 and C60 Performance Technical Reference manuals (410004 and 410005) for additional factors.

This calculation for the electrical limits of the battery is based on the time period required to replace lost charge after a transient cycle and the rate at which it is replaced. To find the system power derating, the transient size and transient interval are required. Deratings are additive for a cycle with more than one size of transient. The upper limit for this derating is based on the maximum charging rate and voltage limit set in the software. This limit is therefore equivalent to the maximum discharge rate, allowed for the battery, so that it is not depleted.

The limits are:

248.4V * 12.8Amps = 3179 Watts.

The 1-hour overload limit is calculated to allow the battery to discharge 30% within the one hour while the BCT is attempting to charge the battery.

The calculation is then:

30% of battery energy = 13Ahr * 12V * 18 cells * 30% = 842 Watt-hours.

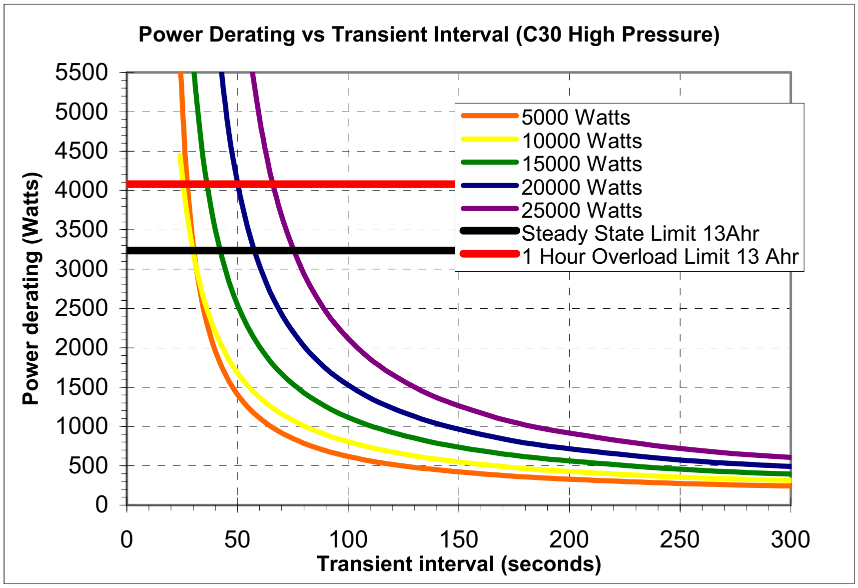
Two examples are provided below to demonstrate calculations for electrical power derating. See Figures 8 and 9 for power derating curves.

<u>Example 1</u>

- 30kW HP natural gas turbine operating at a maximum temperature of 35\C has a temperature-derated output of 24kW. The expected load has a 5kW transient every 40 seconds.
- From the Figure 8, find 40 seconds on the x-axis and point to where it intersects the 5000W line. Read the derating data directly from the y-axis. The power derating is 2000 Watts.
- Net system output is 24kW – 2 kW = 22kW

<u>Example 2</u>

- 5kW transient every minute + 15 kW transient every 2 minutes
- Derating = 1200 W + 1000 W = 2.2kW



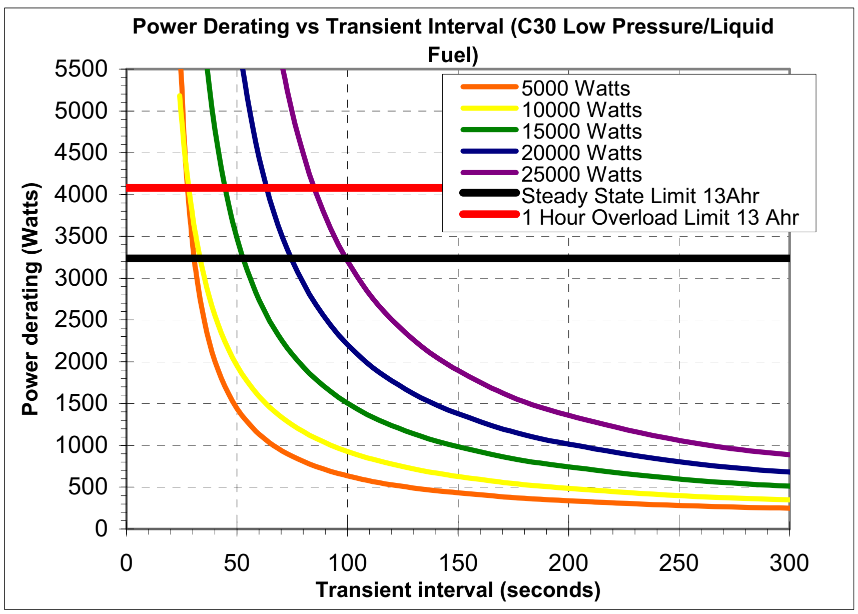


Figure 8. Power Derating of Model C30 Systems

Model C60 Electrical Limits

The C60 charges the battery at 26 amps, and 352 volts during operation for a total power of 9152 Watts.

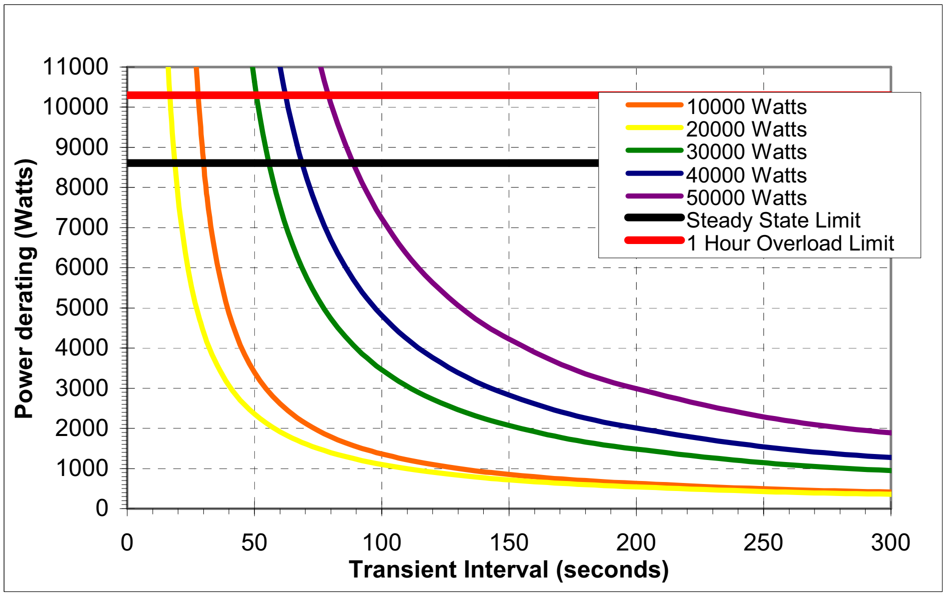


Figure 9. Power Derating of Model C60 System

Capstone Technical Information

If questions arise regarding battery performance after reviewing Capstone documentation, please contact the Technical Support department for assistance and information.

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