

Heat Dissipation of GenStar MPPT Controllers Inside Enclosures



This paper addresses the impact sealed enclosures have on the thermal performance of a GenStar MPPT solar controller placed inside. While a GenStar MPPT's high efficiency minimizes waste energy production in the form of heat, even small amounts of heat can cause a significant temperature rise over time in some cabinet airspaces. Moreover, this temperature rise can be greater if batteries and other heat-generating components are also placed in the same enclosure.

A simplified calculation method is presented to evaluate the ability of the GenStar MPPT to continuously operate during peak temperature conditions inside of an enclosure. The controller's heat sink temperature can be predicted and compared to the derating temperature range limits if the following metrics are known:

- Maximum expected solar array power
- Battery configuration
- Enclosure size
- Enclosure construction
- Controller's power conversion efficiency
- Maximum expected outdoor temperature.

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Introduction

A GenStar MPPT controller can be compromised and even shut off due to high temperatures within its enclosure. In an ideal world, system designers would create a heat transfer simulation of their proposed layout using software to account for all environmental factors and heat sources. However, this is not realistic for many. Project time constraints and lack of access to expensive thermal modeling packages often prevent this from being a practical approach.

Therefore, Morningstar presents a simplified method for conducting a thermal forecast of a GenStar MPPT solar charge controller operating inside an enclosure. It assumes the enclosure is shaded, without wind, with uniformly distributed internal air, and adequate spacing around the enclosure. Although not all real-world influences can be accounted for when using this procedure, it is a convenient way to identify potential overheating conditions early in the design process. System designers can self-impose additional safety factors when performing the calculation to help account for unrepresented factors.

Controller Operation

For a proper system design, one should consider a solar charge controller operating in worst-case environmental conditions. The goal is to ensure that the maximum temperature experienced by the GenStar's heat sink (and by extension the electronic components inside) remains under a safe limit, while ensuring maximum charging current is maintained. Should a safe temperature threshold be exceeded, the controller is programmed to automatically derate output power to reduce onboard temperatures. This way, the life of the controller is maximized and your investment is protected.

Below is a graph of the derating curves for GenStar MPPT models. The 60A, 80A, and 100A models all begin to thermally derate battery charging current when the detected heat sink temperature reaches 80°C. There is a linear derate from 80°C to 90°C. At 90°C, charging current will pause until temperature conditions improve. If 95°C is reached due to load output or outside influences, the system will completely shut down for protection.







Figure 1. Battery Charge Current vs Heat Sink Temperature for GenStar MPPT Models

Calculation Steps

The procedure for evaluating the thermal performance of your GenStar MPPT in an enclosure breaks down into four primary steps:

- 1. Determine the heat dissipation of the controller(s).
- 2. Determine the temperature rise of the enclosure internal air ($\Delta T_{AIR RISE}$).
- 3. Determine the heat sink temperature rise of the controller ($\Delta T_{HS RISE}$).
- 4. Compare the heat sink temperature against controller derating limits.
- 1. Determine the heat dissipation of the controller(s)

Since the GenStar MPPT is designed to be compatible with a large range of PV input voltages and nominal battery output voltages, the amount of heat loss during conversion is a function of the system configuration. Calculating an accurate heat dissipation figure involves determining the controller power conversion efficiency based on the PV array V_{MP} (voltage at maximum power) and P_{MP} (maximum power) parameters.

Morningstar publishes each controller's efficiency curves in their respective operating manual. The GenStar MPPT manual includes all efficiency graphs in *Section 9.0, Technical Specifications*. The same graphs are included in Appendix A of this document for convenience. For each GenStar model, there are unique performance graphs for nominal battery voltages of 12V, 24V, and 48V. Within each graph, several curves are shown when charging from different PV operating voltages (V_{MP}). The X-axis is the output power in Watts, and the Y-axis is the



controller efficiency percentage. An example of one of these graphs for a 100 Amp GenStar model connected to a 12V battery is shown in Figure 2.



Figure 2. Example Efficiency Curves for the GS-MPPT-100M-200V Operating With a 12V Battery Output at Various PV Array Voltage Inputs

The system designer can determine their array's corresponding V_{MP} and P_{MP} based on knowledge of their chosen PV module's I-V curve and array configuration. Then the appropriate efficiency graph corresponding to the intended GenStar model/nominal battery voltage can be selected. A power conversion efficiency percentage can be determined from the graph corresponding to the operating setpoint of V_{MP} and P_{MP} .

Note, P_{MP} of the array is actually the input power from the controller's perspective. Morningstar's efficiency plots are published with controller output power on the X-axis to align with industry standards. However, since the efficiency curves are typically flat throughout the usable range, it is acceptable to use P_{MP} to perform the lookup of controller efficiency.

Using the STC ratings for the array V_{MP} and P_{MP} can provide a conservative estimate for the heat dissipation. In reality, V_{MP} and P_{MP} will be lower than the STC ratings for hot conditions. Array tilt, azimuth, location, season, and mounting technique also play a role, but they are not covered in this document. These drops in real world PV power vs. STC rated power correlate with a reduction of waste heat generated by the controller. The sample calculation later in this paper includes compensations for ambient temperature and PV cell heating (typically +20°C to +40°C) when determining array voltage and power levels.

By knowing the controller efficiency and P_{mp} fed to the controller, the thermal loss (Watts) is calculated as follows:

Equation 1: HEAT_DISSIPATION = $(1 - EFFICIENCY) X P_{MP}$

Decimal efficiency values are used in equations in this document: Example: 98% efficiency = .98

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Multiple Controllers

If there is more than one controller inside the same enclosure, the heat dissipation from each will need to be separately calculated and treated as individual heat sources.

Oversized Arrays

The GenStar MPPT datasheet provides a recommended max array oversizing of 150% relative to the nominal max charging output. The GenStar will limit PV input power to prevent charging current from exceeding the current rating of the controller. Thus, this power-shaving feature places an upper limit for the amount of waste heat capable of being generated by the controller.

MODELS	GS-MPPT-60M-200V		GS-MPPT-80M-200V		GS-MPPT-100M-200V	
Nominal Maximum Output Power	Max Output	Max PV Input*	Max Output	Max PV Input*	Max Output	Max PV Input*
12 Volt	800W	1200W	1075W	1600W	1350W	2000W
24 Volt	1600W	2400W	2150W	3200W	2700W	4000W
48 Volt	3200W	4800W	4300W	6400W	5400W	8000W
Max. Recommended Solar PV Input*	~150% of Nominal Max Output Power ("Max PV Input" Column Above)					

Figure 3. GenStar Nominal Max Output Power vs. Max PV Input Power Ratings

For oversized PV arrays, the maximum input operating power will be limited based on the maximum output power of the controller. The maximum output power during bulk charging will be a bit higher than the "Nominal" Maximum Output Power rating of the controller. This is when the battery voltage is at its highest. Therefore, the highest maximum operating output power can be estimated to be ~ 110% of the Nominal Maximum Output Power rating.

Morningstar's maximum output power rating is based on a charging voltage of 13.33V. When performing thermal calculations, it is important to note that the GenStar output power will actually exceed these values when the battery voltage is above 13.33V. To account for this, the highest maximum operating output power can be estimated to be ~110% of the nominal maximum output power rating. From this, the Maximum PV Input Power Limit ($P_{MAX IN LIM}$) would be:

Equation 2:
$$P_{MAX IN LIM} = 1.1 X (NOM_MAX_PWR_OUTPUT_RATING)/EFFICIENCY$$

Note: Use the efficiency corresponding to the highest power level indicated in the efficiency graphs in the equation above.

If the array $P_{MP} > P_{MAX IN LIM}$, substitute $P_{MAX IN LIM}$ into Equation 1 in place of P_{MP} to determine the maximum heat dissipation:

Equation 3:
$$HEAT_DISSIPATION_{OVERSIZED} = (1 - EFFICIENCY) X P_{MAX IN LIM}$$

To summarize, when determining the heat dissipation experienced by a GenStar MPPT be sure to check P_{MP} against $P_{MAX IN LIM}$ before proceeding. Failure to do so could result in unrealistically high heat projections during the calculation. If array $P_{MP} < P_{MAX IN LIM}$, use equation 1 to determine heat dissipation. If array $P_{MP} > P_{MAX IN LIM}$, use equation 3 to determine heat dissipation.



2. Determine the temperature rise of the enclosure internal air ($\Delta T_{AIR RISE}$)

A graph is provided in Figure 4 (originally sourced from a technical briefing published by Hoffman Enclosures Inc.) for determining the internal air temperature rise of a simple sealed enclosure with internal heat generation.



Figure 4. Sealed Enclosure Temperature Rise vs. Power Dissipation Source: Hoffman Enclosure Inc.'s technical briefing titled "Heat Dissipation in Electrical Enclosures"

The graph (Figure 4) correlates internal air temperature rise on the Y-Axis and heat flux (W/ft²) across all surfaces of the enclosure on the X-Axis. To calculate the enclosure heat flux for your application, perform the following:

- Determine the type of enclosure that best matches the intended choice.
 - Unfinished Aluminum and Stainless Steel Enclosures
 - Painted Metallic and Non-Metallic Enclosures

Note that the temperature rise graph above may not be representative of all enclosures on the market. Higher temperatures can be expected with the unfinished aluminum/stainless steel due to the material's lower emissivity value, which causes lower radiant heat transfer to surroundings. Choosing from the 'unfinished' curve is the conservative choice for this calculation if unsure.

• Calculate the total surface area of all heat dissipating surfaces of the enclosure. Be sure to convert units to feet to correspond with the graph in Figure 4. The basic formula for calculating the total surface area of an enclosure is:

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Equation 4:
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SURFACE\_AREA = 2 \times (WIDTH \times HEIGHT) + 2 \times (DEPTH \times HEIGHT) + 2 \times (WIDTH \times DEPTH)
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Morningstar recommends ignoring the enclosure's mounting surface as a heat transfer surface to stay conservative.

For Ground Mounted Enclosures:





Equation 5:

 $SURFACE_AREA = 2 \times (WIDTH \times HEIGHT) + 2 \times (DEPTH \times HEIGHT) + 1 \times (WIDTH \times DEPTH)$

For Wall Mounted Enclosures: Equation 6: $SURFACE_AREA = 1 \times (WIDTH \times HEIGHT) + 2 \times (DEPTH \times HEIGHT) + 2 \times (WIDTH \times DEPTH)$

- After calculating the heat dissipation of each controller in Step 1, sum all of controller dissipation values along with any other heat sources to be located in the same enclosure.
- Divide the total heat dissipation by the surface area of the enclosure.
- Using the graph in Figure 4, determine the temperature rise of the internal enclosure air over ambient (outdoor) temperature ($\Delta T_{AIR RISE}$).
- 3. Determine the heat sink temperature rise of the controller ($\Delta T_{HS,RISE}$)

The GenStar MPPT heat sink's temperature rise over ambient ($\Delta T_{HS,RISE}$) due to heat dissipation during normal operation is provided in Figure 21 of Appendix B. It is also shown below in Figure 5 below for convenience. Use the appropriate model curve to lookup $\Delta T_{HS RISF}$ on the Y-axis by using the heat dissipation of each controller calculated in Step 1 on the X-axis.

Note that if there is more than one controller inside the enclosure, the controller with the highest heat dissipation will have a higher heatsink temperature rise and be the determining unit for the maximum heatsink temperature in step 4.



Figure 5. GenStar MPPT Heat Sink Temperature Rise (ΔT_{HS}) Over Ambient

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Battery

GND

Batt

Bank

4. Compare the heat sink temperature against controller derating limits

The final step is to sum the highest expected outdoor air temperature, the temperature rise of the air inside the enclosure ($\Delta T_{AIR RISE}$) determined in Step 2, and the heat sink temperature rise of the controller ($\Delta T_{HS RISE}$) determined in Step 3.

Equation 7: $T_{HSMAX} = T_{MAXOUTDOOR} + \Delta T_{AIRRISE} + \Delta T_{HSRISE}$

Although a small amount of High Temperature Current Limiting may be acceptable, Morningstar recommends that the forecasted heat sink temperature (T_{HS MAX}) should not exceed 80°C for the GenStar MPPT to ensure full output charging in any condition.

Sample Calculation

Chosen PV Module STC Ratings & Temperature Coefficients



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19 x 250 W Modules
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Two GenStar MPPT 80 Amp controllers:

GS-MPPT-80M-200V Ratings:

Nom. Max. Output = 2150 W, Max Recommended PV Input = 3200 W Sub-Arrays, each connected to their own GenStar

Sub Array #1: 10 modules; Power (STC) = 2500 W; 5 strings of 2 in series

Sub-Array #2: 9 modules; Power (STC) = 2250 W; 3 strings of 3 in series

Battery System Voltage: 24 VDC Nominal

Highest Temperature for Region $= 36^{\circ}C$

Wall Mounted, Sealed Enclosure:

48" High X 36" Wide X 18" Deep, Painted Metallic Type

Ground Mounted Array (Cell Temp.= + 20°C above Ambient Temperature)

Thermal Dissipation from neighboring components in enclosure = 10 W Maximum



Determine the heat dissipation of the controllers

A. Determine operating temperature of solar panels Cell Temp. = Ambient Temp. + Cell Heating = (36) + (20) = 56°C

B. Calculate V_{MP} of array during hottest conditions

For the individual PV module:

 $V_{MP 56^{\circ}C} = V_{MP STC} X [(1 + (Cell Temp. - STC Temp.) X (Temp. Coef. of V_{mb})]$ $= (42) \times [(1 + (56 - 25) \times (-.0042)])$ = 36.5 V

For the PV sub-arrays:

Sub-array #1: $V_{MPARRAY#1 56^{\circ}C} = V_{MP 56^{\circ}C} \times 2$ (series string arrangement)= 36.5 x 2 = 73 V Sub-array #2: $V_{MPARRAY#256^{\circ}C} = V_{MP56^{\circ}C} \times 3$ (series string arrangement)= 36.5 x 3 = **109.5 V**

C. Calculate Maximum Power (P_{MP}) during hottest conditions

Sub-Array #1:

 $P_{MPARRAY#1 56^{\circ}C} = P_{mp STC} X [(1 + (Cell Temp. - STC Temp.) X (Temp. Coef. of <math>P_{mp})]$ $= 2500 \times [(1 + (56 - 25) \times (-.0039)]$ = 2198 W

Sub-Array #2:

 $P_{MP ARRAY#256^{\circ}C} = P_{MP STC} X [(1 + (Cell Temp. - STC Temp.) X (Temp. Coef. of <math>P_{mb})]$ $= 2250 \times [(1 + (56 - 25) \times (-.0039)])$ = 1978 W

D. Use the applicable efficiency graph to determine the controller efficiency

Refer to Section 9.0. Technical Specifications of the GenStar MPPT manual or in Appendix A of this document. The 24 VDC efficiency graph for the 80A model is shown in Figure 16.

Use the calculated V_{MP} and P_{MP} during hot conditions to find the approximate efficiency of the unit at those conditions.

For Sub-Array #1, Figure 16 shows that 73 V_{MP} lands between the listed plots of $40V_{MP}$ and $80V_{MP}$. At 2198 Watts of array power, the efficiency of the GenStar will be approximately 96.5%.

For Sub-Array #2, Figure 16 shows that 109.5 V_{MP} lands between the listed plots of 80V_{MP} and 120V_{MP}. At 1978 Watts of array power, the efficiency of the GenStar will be approximately 95.5%.







Figure 6. Power Conversion Efficiency Lookup

E. Calculate Thermal Loss of GenStar MPPT Controllers

Check array P_{MP} against controller $P_{MAX IN LIM}$:

Sub-Array #1: $P_{MAX IN LIM#1} = 1.1 \times NOM_MAX_PWR_OUTPUT_RATING / EFFICIENCY$ $= 1.1 \times (2150) / (.965)$ $= 2451 W > P_{MP ARRAY#1 56°C} (2198 W)$, Use array power for determining heat dissipation of GenStar #1. Sub-Array #2: $P_{MAX IN LIM#2} = 1.1 \times NOM_MAX_PWR_OUTPUT_RATING / EFFICIENCY$ $= 1.1 \times (2150) / (.955)$

=2476 W > P_{MP ARRAY#2 56°C} (1978 W), Use array power for determining heat dissipation of GenStar #2.

Though the $P_{mp \ STC}$ ratings of the sub-arrays are both higher than the nominal max output rating (2500 W & 2250 W > 2150 W) of each GS-MPPT-80M-200V controller @ 24 V, they will both operate below the $P_{MAX \ IN \ LIM}$ during hot conditions. Thus, the arrays can operate at full power without current limiting from the GenStar. (See Oversized Array info on page 4).

HEAT DISSIPATION = $(1 - EFFICIENCY) \times P_{MP}$ GenStar #1 Heat Dissipation = $(1 - 0.965) \times 2198 = 76.9 W$ GenStar #2 Heat Dissipation= $(1 - 0.955) \times 1978 = 89.0 W$

Note that GenStar #2 with the smaller array actually dissipates more heat due to the lower efficiency with the higher array voltage.





- 2. Determine the temperature rise of the enclosure internal air ($\Delta T_{AIR RISE}$)
 - A. Type of Enclosure

Wall Mount, Painted Metallic Type

B. Surface Area Contributing to Heat Transfer (Wall Mounted Enclosure)

Surface Area = 1 X (Width X Height) + 2 X (Depth X Height) + 2 X (Width X Depth) = $(36" \times 48") + 2 \times (12" \times 48") + 2 \times (36" \times 12")$ = $3744 in^2$ = $3744 in^2 \times (1 ft^2/144 in^2) = 26.0 ft^2$

C. Sum All Internal Heating

76.9 W + 89.0 W + 10 W = **175.9 W**

D. Calculate Heat Flux of Enclosure

175.9 W / 26.0 $ft^2 = 6.8 W/ft^2$

E. Lookup Temperature Rise ($\Delta T_{AIR RISE}$)

Using the Hoffman Sealed Enclosure Temperature Rise graph, it can be seen that the air temperature rise inside the cabinet is expected to be **18** °C given the internal power dissipation levels and construction of the cabinet.



Figure 7. $\Delta T_{AIR RISE}$ In the Enclosure Lookup

3. Determine the heat sink temperature of the controller (ΔT_{HS RISE})

Using the Heat Sink Temperature Rise vs. Thermal Dissipation graph provided in Appendix B, it can be seen in Figure 8. that the heat sink of GenStar #1 will rise by ~ **21.9** °C due to power conversion loss of 76.9 W, while the heat sink of GenStar #2 will

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rise by ~ **24.2** °C due to the power conversion loss of 89.0 W. GenStar #2 will be the thermal limiting controller for this system design.



Figure 8. $\Delta T_{HS RISE}$ Lookup

4. Compare the heat sink temperature against controller derating limits

 $T_{HS MAX} = T_{MAX OUTDOOR} + \Delta T_{AIR RISE} + \Delta T_{HS RISE}$ = 36.0 + 18.0 + 24.2 = 78.2 °C < 80 °C

Since the maximum heat sink temperature for the hottest GenStar is less than 80 °C, this is considered an acceptable design. Neither of the enclosed GenStar MPPTs in this example are expected to enter into thermal derating, even for the scenario of the hottest day at full PV power. However, that leaves less than 2 °C of margin which is not substantial. As described earlier in the document, there are other environmental factors that can contribute to additional temperature rise (e.g. radiation from the sun) not reflected in this calculation. The following section provides "best practices" to optimize the thermal performance of your controller and techniques to gain additional operating margin.





Thermal Management Best Practices

Morningstar Corporation is committed to supplying the solar off-grid market with charge controllers and inverters with industry leading reliability. A cornerstone of our reliability strategy involves oversizing thermal management components such as heat sinks in our designs. This enables us to offer longer warranty periods than our competition and save installers money over the total life cycle of a system installation.

A rule of thumb prevalent in the electronics cooling industry states that for every 10 degree increase in temperature, a product's life expectancy is cut in half. In reality, the physics of failures involved with electronics is much more complicated than a simple ratio. However, there is truth in the message and solar system designers should be aware of the relationship of temperature and lifespan of all electronics when developing new designs.

The derating scheme of the GenStar MPPT is engineered to ensure that the internal power electronics are never overstressed or damaged. This paper presented a method to ensure that the derate temperature threshold would not be reached in an enclosure on the hottest day; guaranteeing full system output year round. Even when calculations show significant margin, it is always a good idea to take as many steps as is practical to reduce installation temperatures. The following best practices represent tips and suggestions for installers to minimize temperatures and maximize the life of their GenStar MPPT.

• When mounting the GenStar MPPT in an enclosure, ensure proper clearances are maintained as shown in Figure 9. Failure to maintain these clearances may result in higher operating temperatures than what is projected using the method in this paper.



Figure 9. Required Mounting Clearances for Proper Airflow

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- Due to natural convection, the air at the bottom of a sealed enclosure can be several degrees cooler than at the top, so it is better to mount towards the bottom of the enclosure if given the choice.
- The GenStar MPPT is recommended to be mounted vertically on a wall as depicted above in Figure 9. The GenStar not only features a large extruded aluminum heat sink on the face of the controller, but the backside structure is manufactured as a finned aluminum casting. This casting body also plays a sizable role in dissipating heat. The buoyancy driven airflow from natural convection works best when air is allowed to rise unimpeded through the fin channels on the front and back simultaneously.

For spatially constrained installations, mounting the unit horizontally can still work since the large heat sink on the face does the majority of the heat transfer to surrounding air. A reduction in thermal performance is expected from being horizontal. Contact Morningstar technical support for further information regarding horizontal mounting for your application. See Figure 10 for depictions of the recommended vertical mounting orientation, the degraded horizontal mounting orientation, and improper mounting orientations.



Figure 10. Proper, Degraded, and Improper Mounting Orientations

- Moving to a larger enclosure is a cost effective means for reducing internal air temperature rise if space is not at a premium. The larger the enclosure, the lower the thermal impedance to outdoor air from the controller.
- Solar heat shields are a relatively low cost method for shading an enclosure. Many electrical enclosures offer compatible covers and panels that help reflect solar radiation, and minimize solar heat gain experienced by them.



Page 14



- "Sub-ambient" coatings are a recent technology development for passive cooling outdoor objects. Surfaces with these coatings can have a lower temperature than ambient surroundings, even under direct sunlight. They work by reflecting as much incident solar radiation as possible, while simultaneously allowing for infrared radiation (IR) emissions from the source that they are applied to. The IR emissions occur at a particular wavelength that corresponds with our atmosphere's "infrared window," allowing space to absorb the unwanted heat. Although not yet common, lining the exterior of electrical enclosures with "sub-ambient" coatings may become the norm in the near future for hot climates.
- Using an enclosure with upper and lower ventilation is a very effective passive cooling technique. Internal air temperature rise can be greatly reduced without adding additional complexity from a fan. This would typically be implemented when the enclosure is sheltered from the elements. However, ingress protection (IP) methods may be necessary to avoid water or debris from entering the enclosure.
- For highly challenged temperature environments, the addition of a fan may be warranted. Even a sealed enclosure can still benefit from a fan circulating internal air. A typical 120 mm axial fan only adds a modest (several Watts) of heat to the enclosure internal air space. However, there will likely be a lower enclosure air temperature overall. This is due to the enhanced convective heat transfer from the controller heat sink and to the enclosure walls, as a result of the extra velocity of the air. The forced convection from the fan also adds turbulence to the air helping to break up boundary layers along surfaces, increasing convection. In addition, a fan will mix the enclosure air and reduce temperature gradients, especially helpful if the controller must be mounted at the top of a cabinet.

A ReadyRelay is the perfect option for directly controlling a fan. Like all Morningstar ReadyBlocks, the ReadyRelay is designed to directly mount onboard the GenStar MPPT in a seamless fashion. The ReadyRelay can be set to trigger a fan based on heat sink temperature. In this way, the life of the fan is extended and energy harvest is maximized for all conditions.

For highly challenged temperature environments, using a controller with a higher battery current rating is beneficial for gaining additional thermal margin. Alternatively, an additional charge controller (or more) can be added to the system using smaller PV arrays for each controller. By operating each controller at a lower capacity, the ΔT_{HS RISE} component mentioned in this white paper would be reduced. Essentially, the controller heat losses would be split up across more heat sink surfaces in the mix.

All else equal, the $\Delta T_{AIR RISE}$ inside the hypothetical enclosure would be the same since the total heat load would be the same. Depending on how the PV array was split up across controllers, V_{mp} might be reduced resulting in a higher power conversion efficiency. In that case, there would be a reduction to the $\Delta T_{AIR RISE}$ component.





Appendix A - GenStar MPPT Efficiency Graphs



Figure 11. Efficiency vs. Output Power Curves for the GS-MPPT-100M-200V Operating With a 12 V Battery Output at 20 Vmp, 80 Vmp, 120 Vmp, and 160 Vmp Inputs



Figure 12. Efficiency vs. Output Power Curves for the GS-MPPT-100M-200V Operating With a 24 V Battery Output at 40 Vmp and 120 Vmp Inputs

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Page 16





Figure 13. Efficiency vs. Output Power Curves for the GS-MPPT-100M-200V Operating With a 48 V Battery Output at 52 Vmp and 60 Vmp Inputs



Figure 14. Efficiency vs. Output Power Curves for the GS-MPPT-100M-200V Operating With a 48 V Battery Output at 52 Vmp, 80 Vmp, and 160 Vmp Inputs

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Page 17





Figure 15. Efficiency vs. Output Power Curves for the GS-MPPT-80M-200V Operating With a 12 V Battery Output at 20 Vmp, 40 Vmp, 80 Vmp, 120 Vmp, and 160 Vmp Inputs



Figure 16. Efficiency vs. Output Power Curves for the GS-MPPT-80M-200V Operating With a 24 V Battery Output at 40 Vmp, 80 Vmp, 120 Vmp, and 160 Vmp Inputs

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Figure 17. Efficiency vs. Output Power Curves for the GS-MPPT-80M-200V Operating With a 48 V Battery Output at 80 Vmp, 120 Vmp, and 160 Vmp Inputs



Figure 18. Efficiency vs. Output Power Curves for the GS-MPPT-60M-200V Operating With a 12 V Battery Output at 20 Vmp, 40 Vmp, 80 Vmp, 120 Vmp, and 160 Vmp Inputs

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Figure 19. Efficiency vs. Output Power Curves for the GS-MPPT-60M-200V Operating With a 12 V Battery Output at 40 Vmp, 80 Vmp, 120 Vmp, and 160 Vmp Inputs



Figure 20. Efficiency vs. Output Power Curves for the GS-MPPT-60M-200V Operating With a 12 V Battery Output at 80 Vmp, 120 Vmp, and 160 Vmp Inputs

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Appendix B - GenStar MPPT Heat Sink Rise vs. **Thermal Dissipation**



Figure 21. GenStar MPPT Heat Sink Temperature Rise (ΔT_{HS}) Over Ambient

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