

Maximum Power Point Tracking With the bq24650 Charger

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ABSTRACT

This application report describes a solution to track the maximum power point of a solar panel using a negative temperature coefficient (NTC) thermistor with the bq24650. The basic functionality of a solar panel is described. The use of a spreadsheet tool to aid in the setup process is described as well.

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1 Introduction

The bq24650 is a highly integrated, switch-mode, battery charge controller that is capable of using a solar panel as the input power source. The bq24650 has the ability to aid in tracking the solar panel's maximum power point with the use of the MPPSET pin. [Figure 1](#) shows the typical application circuit of the bq24650 controller.

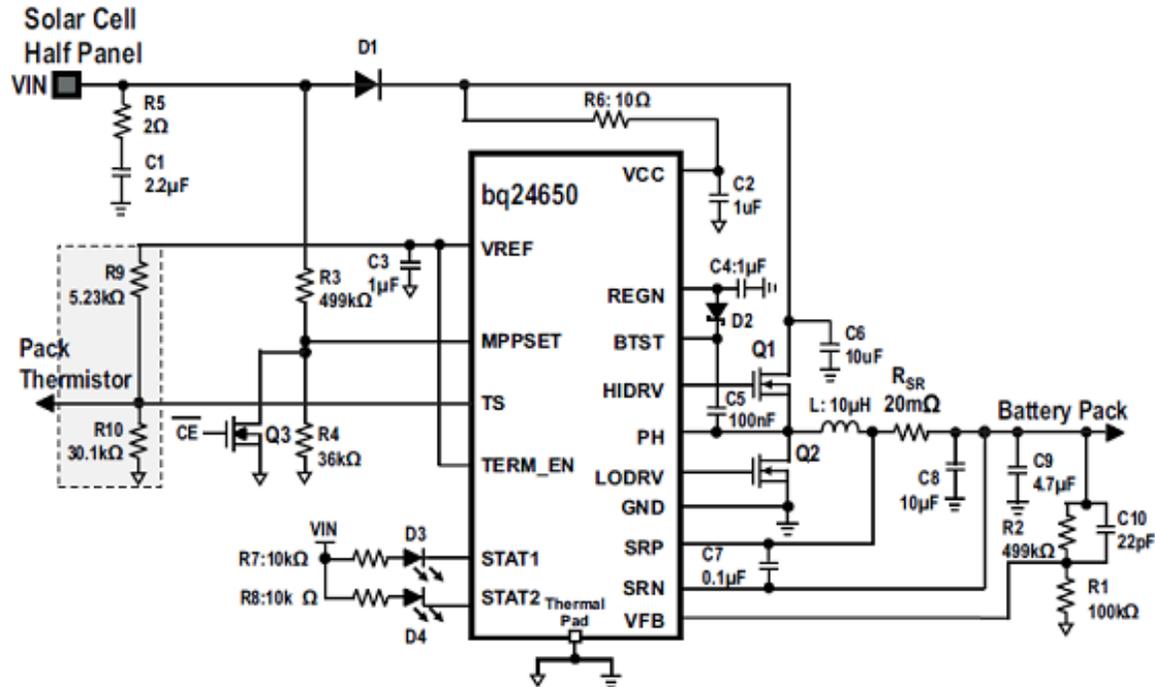


Figure 1. bq24650 Typical Application Circuit

A solar panel consists of a number of interconnected solar cells. The individual solar cells are responsible for converting light into electricity. Solar cells electrically connected in series increase the output voltage while connecting solar cells electrically in parallel increase the output current. When dealing with a solar panel, an important concept to understand is the maximum power point (MPP) of the solar panel. Every solar panel has a specific voltage and current at which the panel can provide maximum power. The MPP can be seen from the solar panel's I-V curve. With no output current, the solar cell voltage is at its maximum value, but the output power is 0 W. As the current pulled from the solar panel increases, the solar panel's output voltage decreases. This behavior leads to a desirable situation called the MPP (maximum power point) where the panel delivers maximum power. However, if current continues to be pulled from the solar panel past the optimum point, the solar panel's voltage begins to drop dramatically until the voltage goes to 0 V and simultaneously reducing the output power to 0 W. Along with the I-V curve and other graphical data, solar panel manufacturers typically provide the information found in [Table 1](#) along with test conditions like temperature and irradiance.

Table 1. Typical Solar Panel Characteristics

CHARACTERISTIC	DESCRIPTION
Open-Circuit Voltage (V_{OC})	Solar panel with no load
Short-Circuit Current (I_{SC})	Solar panel current without voltage
Maximum Power Point Voltage (V_{MP})	Solar panel voltage at maximum power point typically specified at 25°C
Maximum Power Point Current (I_{MP})	Solar panel current at maximum power point typically specified at 25°C
Maximum Power (P_{MAX})	Solar panel maximum power typically specified at 25°C

The solar panel referenced in this application report is the LR0GC02 solar panel created by Sharp. Figure 2 shows the solar panel's I-V curve. Power is represented by the dotted lines.

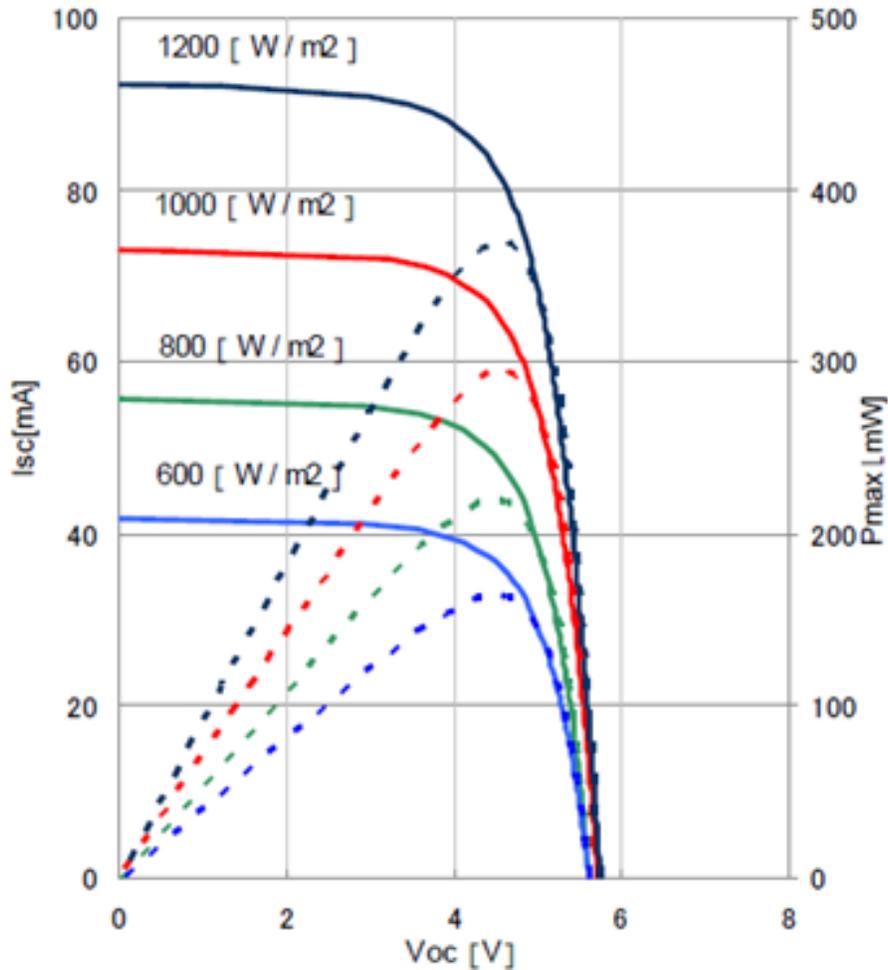


Figure 2. LR0GC02 I-V Curve

Figure 2 shows how the irradiance affects the maximum power output from the panel. Temperature is another variable that affects the maximum output power of the panel. Figure 3 shows the LR0GC02 solar panel's characteristics over temperature.

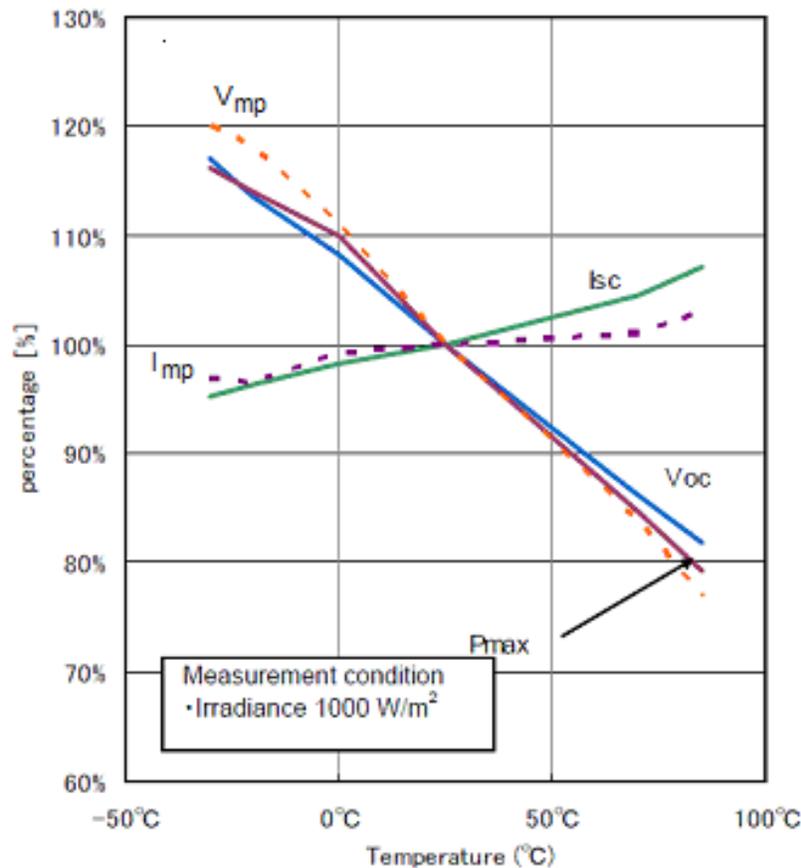


Figure 3. Solar Panel Characteristics vs Temperature

Figure 3 displays the maximum power voltage (V_{MP}) with the dotted orange trace, the maximum power current (I_{MP}) with the dotted purple trace, the maximum power (P_{MAX}) with the solid purple trace, the open-circuit voltage (V_{OC}) with the solid blue trace and the short-circuit current (I_{SC}) with the solid green trace. Each characteristic, V_{MP} , I_{MP} , I_{SC} , V_{OC} , and P_{MAX} , are plotted over temperature with respect to their value at 25°C. Each characteristic's trace intersects the 100% mark of the y-axis at the 25°C mark of the x-axis. Table 2 verifies this information. A solar panel's temperature coefficient provides information on how a specified characteristic changes over temperature. Ideally the open-circuit voltage (V_{OC}) slope matches the maximum power voltage (V_{MP}) slope, and the short-circuit current (I_{SC}) slope matches the maximum power current (I_{MP}). For the purpose of this application report and the Excel™ spreadsheet tool, the temperature coefficient refers to the slope of the MPP voltage (V_{MP}) with respect to temperature.

When using a solar panel, it is desirable to select an operating point that provides the maximum output power. Charger ICs like the bq24650 incorporate MPPSET circuitry to provide this functionality. Resistors R3 and R4 in Figure 1 define a minimum operating voltage for the solar panel. As the bq24650 pulls current from the solar panel to charge the battery, the solar panel output voltage drops. The MPPSET circuitry becomes active if the solar panel voltage drops below the set point. This circuitry reduces the charge current to regulate the solar panel V_{MP} which maximizes power. With the setup of R3 and R4 in Figure 1, the V_{MP} of the solar panel is set for a specific temperature, typically 25°C. Due to the V_{MP} changing with temperature, optimizing the bq24650 setup for a specific temperature inhibits the solar panel from operating at the proper V_{MP} point if the temperature varies. However, by using a negative temperature coefficient (NTC) thermistor, a low-cost solution has been developed that allows the V_{MP} to be tracked over temperature. Figure 4 shows the setup.

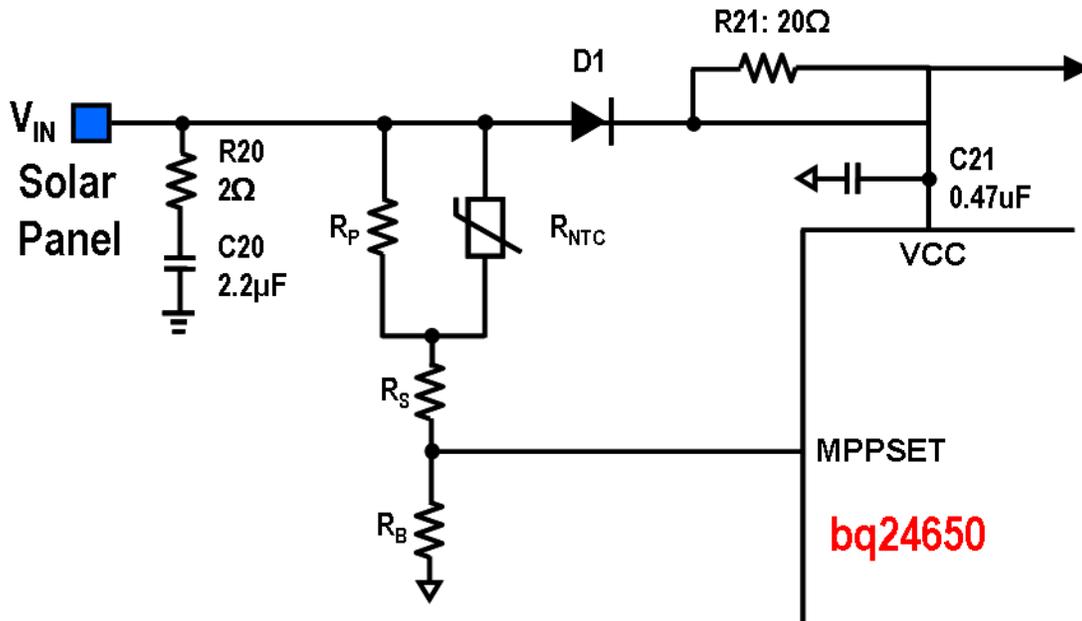


Figure 4. MPP Tracking Resistor Network Schematic

The resistance value of the thermistor varies with temperature. This characteristic of the thermistor is what allows the circuit in Figure 4 to adjust the V_{MP} of the solar panel when the temperature varies. It is necessary to use a NTC thermistor because as temperature increases the solar panels V_{MP} decreases. Figure 3 displays this characteristic of the solar panel. A NTC thermistor decreases in resistance as the temperature increases; conversely, a positive temperature coefficient (PTC) thermistor increases in resistance as the temperature increases. Because the MPPSET pin must be regulated to 1.2 V, and the voltage supplied by the solar panel decreases as the temperature increases, Equation 1 shows that a NTC thermistor is necessary to properly track the V_{MP} .

$$V_{MPPSET} = \frac{V_{IN} \times R_B}{(R_{EQ} + R_B)} \quad (1)$$

Where:

$$R_{EQ} = R_P \parallel R_{NTC} + R_S$$

V_{MPPSET} = bq24650 maximum power point set voltage (fixed at 1.2 V)

V_{IN} = the solar cell's operating voltage

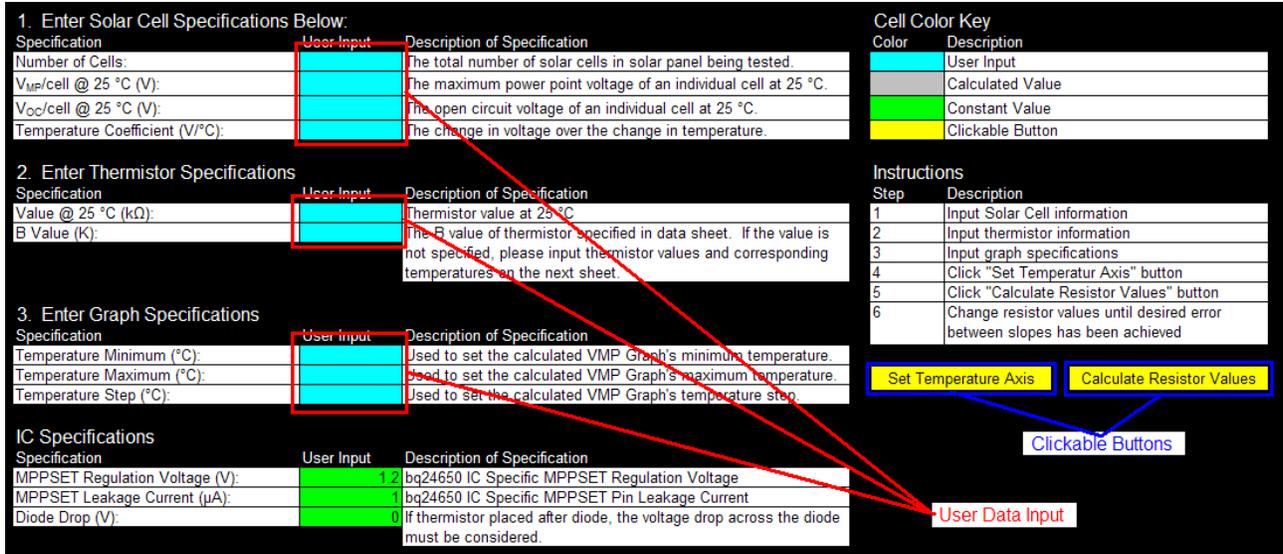
R_P and R_S are necessary due to how the thermistor's resistance varies logarithmically over temperature. The added parallel and series resistance helps to make the total change in resistance, R_{EQ} , over temperature more linear. This allows the circuit to match the linear characteristic of the solar panel's V_{MP} over temperature. In order to solve for the optimal parallel and series resistance values, some complex mathematical analysis is required. To make the process of finding the optimal values easier, an Excel spreadsheet has been developed. The spreadsheet takes care of the complicated mathematics and provides the user with optimal resistance values.

2 Spreadsheet Overview

This Excel spreadsheet aids customers in the design process of using a solar panel with the bq24650. The spreadsheet is responsible for providing the customer with recommended resistor values based on the specific solar panel and NTC thermistor within the customer's application. The customer has the ability to adjust the resistor values and see a graphical representation of how well the slope of the resistor network connected to the bq24650 tracks with the V_{MP} slope of the solar panel. Figure 4 shows a schematic of the network implemented.

Figure 5 shows the top part of the spreadsheet tool. This part of the tool is where the user enters

information about the solar panel and NTC thermistor and specifies the temperature axis upper and lower limit as well as the step between temperature values. After the user has input all of the necessary information, the available, clickable buttons first set the temperature axis and then calculate the recommended resistor values. Figure 5 shows the user input cells highlighted in red boxes and the clickable buttons highlighted in blue boxes.



1. Enter Solar Cell Specifications Below:

Specification	User Input	Description of Specification
Number of Cells:		The total number of solar cells in solar panel being tested.
$V_{MP}/cell @ 25^{\circ}C (V)$:		The maximum power point voltage of an individual cell at 25 °C.
$V_{OC}/cell @ 25^{\circ}C (V)$:		The open circuit voltage of an individual cell at 25 °C.
Temperature Coefficient (V/°C):		The change in voltage over the change in temperature.

Cell Color Key

Color	Description
Light Blue	User Input
Light Green	Calculated Value
Light Yellow	Constant Value
Light Orange	Clickable Button

2. Enter Thermistor Specifications

Specification	User Input	Description of Specification
Value @ 25 °C (kΩ):		Thermistor value at 25 °C
B Value (K):		The B value of thermistor specified in data sheet. If the value is not specified, please input thermistor values and corresponding temperatures on the next sheet.

3. Enter Graph Specifications

Specification	User Input	Description of Specification
Temperature Minimum (°C):		Used to set the calculated VMP Graph's minimum temperature.
Temperature Maximum (°C):		Used to set the calculated VMP Graph's maximum temperature.
Temperature Step (°C):		Used to set the calculated VMP Graph's temperature step.

IC Specifications

Specification	User Input	Description of Specification
MPPSET Regulation Voltage (V):	1.2	bq24650 IC Specific MPPSET Regulation Voltage
MPPSET Leakage Current (μA):		bq24650 IC Specific MPPSET Pin Leakage Current
Diode Drop (V):	0	If thermistor placed after diode, the voltage drop across the diode must be considered.

Instructions

Step	Description
1	Input Solar Cell information
2	Input thermistor information
3	Input graph specifications
4	Click "Set Temperature Axis" button
5	Click "Calculate Resistor Values" button
6	Change resistor values until desired error between slopes has been achieved

Clickable Buttons: Set Temperature Axis, Calculate Resistor Values

User Data Input: 1.2, 0

Figure 5. Top Section of Spreadsheet Tool

Figure 6 shows the bottom part of the spreadsheet tool. This part of the tool allows the user to see the schematic as well as the recommended resistor values. Below the recommended values, the user can input different resistor values in order to see if they provide a more accurate V_{MP} slope compared to the solar panel's V_{MP} slope. Figure 6 shows the recommended resistor values highlighted in a red box and the user-chosen resistor values highlighted in a blue box. The Excel spreadsheet calculates the exact recommended resistor values. The user must then enter a specific resistor value based on standard resistor values.

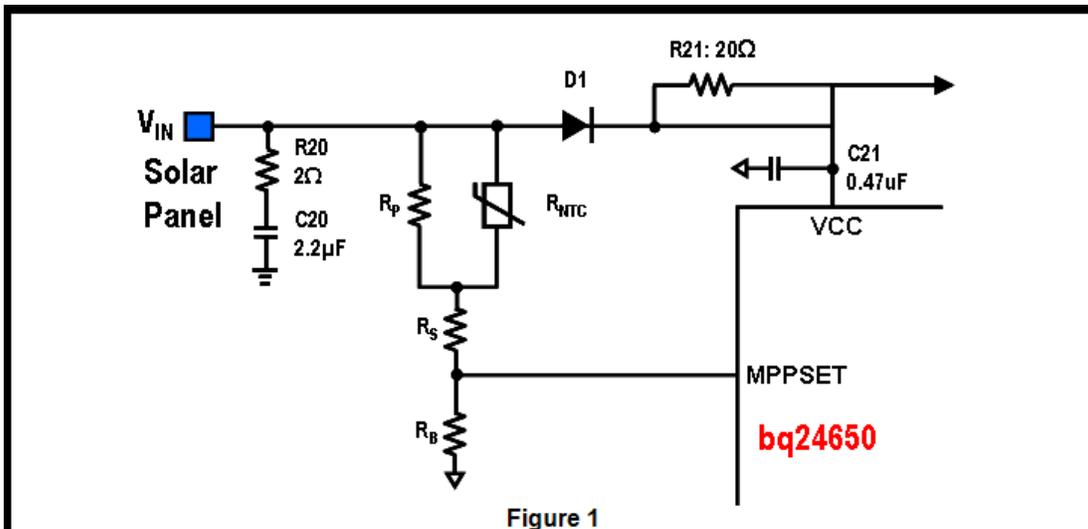


Figure 1

Recommended Starting Point Resistor Values		
Resistor	Value	Note(s)
R _P (kΩ)		Refer to Figure 1 for location.
R _S (kΩ)		Refer to Figure 1 for location.
R _B (kΩ)		Refer to Figure 1 for location.

User Chosen Resistor Values		
Resistor	Value	Notes(s)
R _P (kΩ)		Refer to Figure 1 for location. Choose Different values for optimal result.
R _S (kΩ)		Refer to Figure 1 for location. Choose Different values for optimal result.
R _B (kΩ)		Refer to Figure 1 for location. Choose Different values for optimal result.

Figure 6. Bottom Section of Spreadsheet Tool

Two graphs appear after the Calculate Resistor Values button has been clicked. Both graphs appear below the User Chosen Resistor Values section. The graph on the left side of the page represents voltage with respect to temperature. This graph displays the V_{MP} of the solar panel versus temperature (blue trace), V_{MP} calculated using the recommended resistor values versus temperature (magenta trace) and V_{MP} calculated using the user chosen resistor values versus temperature (yellow trace). The graph on the right represents the error of the calculated V_{MP} with respect to the solar panel's V_{MP} versus temperature. This graph displays the error in the V_{MP} calculated with the recommended resistor values (blue trace) and the error in the V_{MP} calculated with the user-chosen resistor values (magenta trace). Figure 7 displays the two graphs that can be seen in the spreadsheet tool. All of the data used to create the graphs can be found on the Data tab of the Excel workbook. Each column has an explanation as to what the data in the column represents.

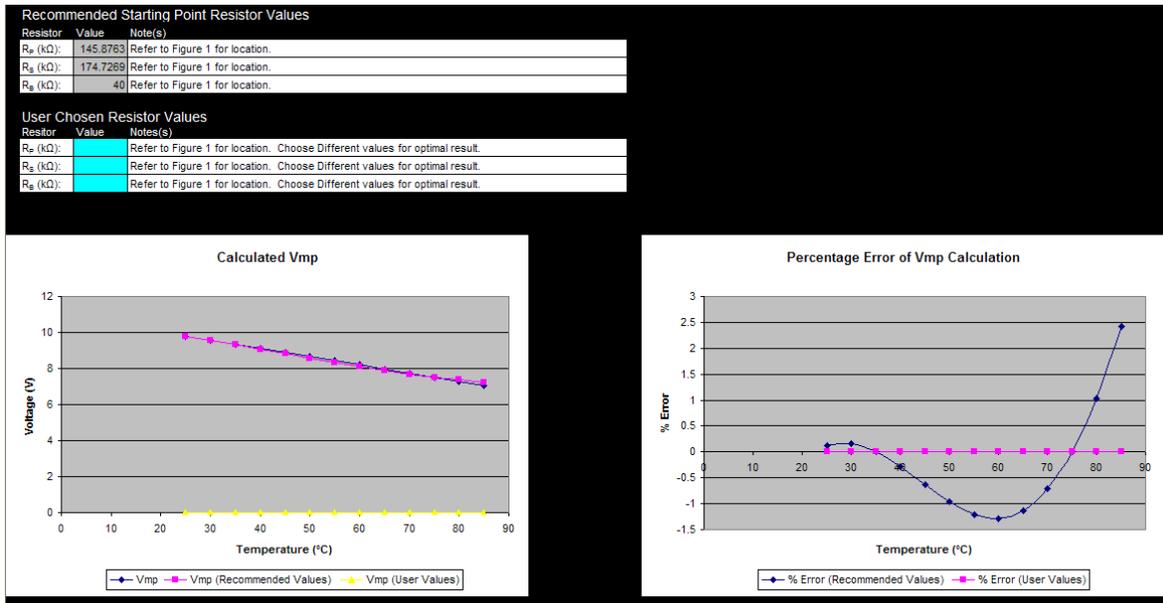


Figure 7. Graph Section of Spreadsheet Tool

3 Solar Panel Example Using Spreadsheet

The following example demonstrates how to use the spreadsheet tool.

3.1 Solar Panel Specifications

As previously mentioned, the solar panel used for initial testing was the Sharp LR0GC02. The data sheet specifies that this is a solar panel with 10 solar cells interconnected in series. Table 2 shows the basic information of the solar panel. The test conditions are specified to be a temperature of 25°C ± 3°C and 1000 W/m² irradiance.

Table 2. LR0GC02 Characteristics

Symbol	Characteristic	Min	Typ	Max	Unit
V _{OC}	Open-circuit voltage	5.2	5.7	—	V
I _{SC}	Short-circuit current	62	75	—	mA
V _{MP}	Maximum power voltage	3.8	4.5	—	V
I _{MP}	Maximum power current	48	65	—	mA
P _{MAX}	Maximum power	240	300	—	mW

The first user input cell in the Solar Panel Specifications section asks for the number of cells; in this example, that number is 10. The next cell asks for the V_{MP}/cell at 25°C; for this example, that number is 4.5/10 = 0.45 V. The next cell asks for the V_{OC}/cell at 25°C; for this example, that number is 5.7/10 = 0.57 V. Finally, the last cell asks for the temperature coefficient in V/°C of the solar panel. The data sheet provides the point at 25°C, but another point is needed in order to calculate the V_{MP} slope over temperature. Figure 3 displays the graph, found in the data sheet, which helps provide another point in order to calculate the slope. According to the graph, the dotted orange line represents the V_{MP} over temperature. Around 75°C, the line appears to be roughly at 80% of the V_{MP} value at 25°C. Therefore, the second point is at a temperature of 75°C with a voltage of 0.8 × 4.5 = 3.6 V. Note that the V_{MP} value at any two temperatures can be used. Using Equation 2 for slope,

$$m = \frac{(y_2 - y_1)}{(x_2 - x_1)} \tag{2}$$

Where:

y_2 = the V_{MP} value at the second temperature = 3.6 V
 y_1 = the V_{MP} value at the first temperature = 5.7 V
 x_2 = the second temperature = 75°C
 x_1 = the first temperature = 25°C.

These values yield a temperature coefficient of -0.042 V/°C. Notice that the temperature coefficient is negative. This characteristic makes sense because as the temperature rises, the efficiency of the panel drops. [Figure 8](#) shows all the values previously discussed placed into the proper cells of the spreadsheet tool. The cells are highlighted in the red box.

1. Enter Solar Cell Specifications Below:			Cell Color Key	
Specification	User Input	Description of Specification	Color	Description
Number of Cells:	10	The total number of solar cells in solar panel being tested.	Light Blue	User Input
V_{MP}/cell @ 25 °C (V):	0.45	The maximum power point voltage of an individual cell at 25 °C.	Light Grey	Calculated Value
V_{OC}/cell @ 25 °C (V):	0.57	The open circuit voltage of an individual cell at 25 °C.	Light Green	Constant Value
Temperature Coefficient (V/°C):	-0.042	The change in voltage over the change in temperature.	Yellow	Clickable Button

2. Enter Thermistor Specifications			Instructions	
Specification	User Input	Description of Specification	Step	Description
Value @ 25 °C (kΩ):		Thermistor value at 25 °C	1	Input Solar Cell information
B Value (K):		The B value of thermistor specified in data sheet. If the value is not specified, please input thermistor values and corresponding temperatures on the next sheet.	2	Input thermistor information
			3	Input graph specifications
			4	Click "Set Temperature Axis" button
			5	Click "Calculate Resistor Values" button
			6	Change resistor values until desired error between slopes has been achieved

3. Enter Graph Specifications			Buttons	
Specification	User Input	Description of Specification		
Temperature Minimum (°C):		Used to set the calculated VMP Graph's minimum temperature.		
Temperature Maximum (°C):		Used to set the calculated VMP Graph's maximum temperature.		
Temperature Step (°C):		Used to set the calculated VMP Graph's temperature step.		

IC Specifications		
Specification	User Input	Description of Specification
MPPSET Regulation Voltage (V):	1.2	bq24650 IC Specific MPPSET Regulation Voltage
MPPSET Leakage Current (μA):		bq24650 IC Specific MPPSET Pin Leakage Current
Diode Drop (V):	0	If thermistor placed after diode, the voltage drop across the diode must be considered.

Step	Description
Set Temperature Axis	Calculate Resistor Values

Figure 8. Solar Panel Specifications

3.2 Thermistor Specifications

The next section in the spreadsheet tool is for the thermistor. From the data sheet, the resistance value of the thermistor at 25°C can be found as well as the B-value of the thermistor. The B-value of the thermistor is somewhat complex and beyond the scope of this application report. However, the B-value can be thought of as a representation of how the resistance value of the thermistor changes over temperature when used in the proper equation. Typically, the B-value is given over a temperature range; for instance, B25/85 is representative of the range from 25°C – 85°C and also the value used in this example. This example uses a 470-kΩ thermistor at 25°C with a B25/85 value of 4570 K. The B-value has units of Kelvin (K) due to the equation that uses the B-value in order to extract information about the thermistor over temperature. [Figure 9](#) shows all the values previously discussed placed into the proper cells of the spreadsheet tool. The cells are highlighted in the red box.

1. Enter Solar Cell Specifications Below:			Cell Color Key	
Specification	User Input	Description of Specification	Color	Description
Number of Cells:	10	The total number of solar cells in solar panel being tested.	Light Blue	User Input
$V_{MP}/cell @ 25^{\circ}C (V)$:	0.45	The maximum power point voltage of an individual cell at 25 °C.	Light Grey	Calculated Value
$V_{OC}/cell @ 25^{\circ}C (V)$:	0.57	The open circuit voltage of an individual cell at 25 °C.	Light Green	Constant Value
Temperature Coefficient (V/°C):	-0.042	The change in voltage over the change in temperature.	Yellow	Clickable Button

2. Enter Thermistor Specifications			Instructions	
Specification	User Input	Description of Specification	Step	Description
Value @ 25 °C (kΩ):	470	Thermistor value at 25 °C	1	Input Solar Cell information
B Value (K):	4570	The B value of thermistor specified in data sheet. If the value is not specified, please input thermistor values and corresponding temperatures on the next sheet.	2	Input thermistor information
			3	Input graph specifications
			4	Click "Set Temperature Axis" button
			5	Click "Calculate Resistor Values" button
			6	Change resistor values until desired error between slopes has been achieved

3. Enter Graph Specifications			Buttons	
Specification	User Input	Description of Specification	Set Temperature Axis	Calculate Resistor Values
Temperature Minimum (°C):		Used to set the calculated VMP Graph's minimum temperature.	Yellow	Yellow
Temperature Maximum (°C):		Used to set the calculated VMP Graph's maximum temperature.	Yellow	Yellow
Temperature Step (°C):		Used to set the calculated VMP Graph's temperature step.	Yellow	Yellow

IC Specifications		
Specification	User Input	Description of Specification
MPPSET Regulation Voltage (V):	1.2	bq24650 IC Specific MPPSET Regulation Voltage
MPPSET Leakage Current (µA):	1	bq24650 IC Specific MPPSET Pin Leakage Current
Diode Drop (V):	0	If thermistor placed after diode, the voltage drop across the diode must be considered.

Figure 9. Thermistor Specifications

3.3 Graph Specifications

The next section of the spreadsheet tool allows the user to adjust the graph x-axis settings. The x-axis is the temperature axis. The minimum and maximum temperature can be specified. The step size between the minimum and maximum can be specified as well. For this example, the minimum temperature was set to 20°C, the maximum set to 80°C, and the step size set to 5 °C. Figure 10 shows all the values previously discussed placed into the proper cells of the spreadsheet tool. The cells are highlighted in the red box.

1. Enter Solar Cell Specifications Below:			Cell Color Key	
Specification	User Input	Description of Specification	Color	Description
Number of Cells:	10	The total number of solar cells in solar panel being tested.	Light Blue	User Input
$V_{MP}/cell @ 25^{\circ}C (V)$:	0.45	The maximum power point voltage of an individual cell at 25 °C.	Light Grey	Calculated Value
$V_{OC}/cell @ 25^{\circ}C (V)$:	0.57	The open circuit voltage of an individual cell at 25 °C.	Light Green	Constant Value
Temperature Coefficient (V/°C):	-0.042	The change in voltage over the change in temperature.	Yellow	Clickable Button

2. Enter Thermistor Specifications			Instructions	
Specification	User Input	Description of Specification	Step	Description
Value @ 25 °C (kΩ):	470	Thermistor value at 25 °C	1	Input Solar Cell information
B Value (K):	4570	The B value of thermistor specified in data sheet. If the value is not specified, please input thermistor values and corresponding temperatures on the next sheet.	2	Input thermistor information
			3	Input graph specifications
			4	Click "Set Temperature Axis" button
			5	Click "Calculate Resistor Values" button
			6	Change resistor values until desired error between slopes has been achieved

3. Enter Graph Specifications			Buttons	
Specification	User Input	Description of Specification	Set Temperature Axis	Calculate Resistor Values
Temperature Minimum (°C):	20	Used to set the calculated VMP Graph's minimum temperature.	Yellow	Yellow
Temperature Maximum (°C):	80	Used to set the calculated VMP Graph's maximum temperature.	Yellow	Yellow
Temperature Step (°C):	5	Used to set the calculated VMP Graph's temperature step.	Yellow	Yellow

IC Specifications		
Specification	User Input	Description of Specification
MPPSET Regulation Voltage (V):	1.2	bq24650 IC Specific MPPSET Regulation Voltage
MPPSET Leakage Current (µA):	1	bq24650 IC Specific MPPSET Pin Leakage Current
Diode Drop (V):	0	If thermistor placed after diode, the voltage drop across the diode must be considered.

Figure 10. Graph Specifications

3.4 Further User Interaction

After the Solar Cell Specifications, Thermistor Specifications, and Graph Specifications sections have been filled out, click the Set Temperature Axis button on the right side of the spreadsheet tool. After the axis has been set, the user is prompted to click the Calculate Resistor Values button. Figure 11 displays the prompt the user sees.

1. Enter Solar Cell Specifications:			Cell Color Key	
Specification	User Input	Description of Specification	Color	Description
Number of Cells:	10	The total number of solar cells in solar panel being tested.	Light Blue	User Input
$V_{MP}/cell @ 25^\circ C$ (V):	0.45	The maximum power point voltage of an individual cell at 25 °C.	Light Green	Calculated Value
$V_{OC}/cell @ 25^\circ C$ (V):	0.57	The open circuit voltage of an individual cell at 25 °C.	Light Yellow	Constant Value
Temperature Coefficient (V/°C):	-0.042	The change in voltage over the change in temperature.	Light Purple	Clickable Button

2. Enter Thermistor Specifications			Instructions	
Specification	User Input	Description of Specification	Step	Description
Value @ 25 °C (kΩ):	470	Thermistor value at 25 °C	1	Input Solar Cell information
B Value (K):	4570	The B value of thermistor. If not specified, please enter a value between 2000 and 5000.	2	Input thermistor information
			3	Input graph specifications
			4	Click "Set Temperature Axis" button
			5	Click "Calculate Resistor Values" button
			6	Change resistor values until desired error between slopes has been achieved

3. Enter Graph Specifications		
Specification	User Input	Description of Specification
Temperature Minimum (°C):	20	Used to set the calculated VMP Graph's minimum temperature.
Temperature Maximum (°C):	80	Used to set the calculated VMP Graph's maximum temperature.
Temperature Step (°C):	5	Used to set the calculated VMP Graph's temperature step.

IC Specifications		
Specification	User Input	Description of Specification
MPPSET Regulation Voltage (V):	1.2	bq24650 IC Specific MPPSET Regulation Voltage
MPPSET Leakage Current (µA):	1	bq24650 IC Specific MPPSET Pin Leakage Current
Diode Drop (V):	0	If thermistor placed after diode, the voltage drop across the diode must be considered.

Microsoft Excel

Click the calculate starting point resistor values button.

OK

Set Temperature Axis
Calculate Resistor Values

Figure 11. User Prompt

Simply click the OK button in the prompt, and then click the Calculate Resistor Values button that is located to the right of the Set Temperature Axis button. After the Calculate Resistor Values button has been clicked, the calculation is made and two graphs appear below the User Chosen Resistor Values section. Initially, all the points for the V_{MP} of the user-chosen values and the error based on the user-chosen values are 0. This is because the user has not yet entered any information. Figure 12 displays this initial state of the graphs. The empty User Chosen Resistor Values section is highlighted in the red box.

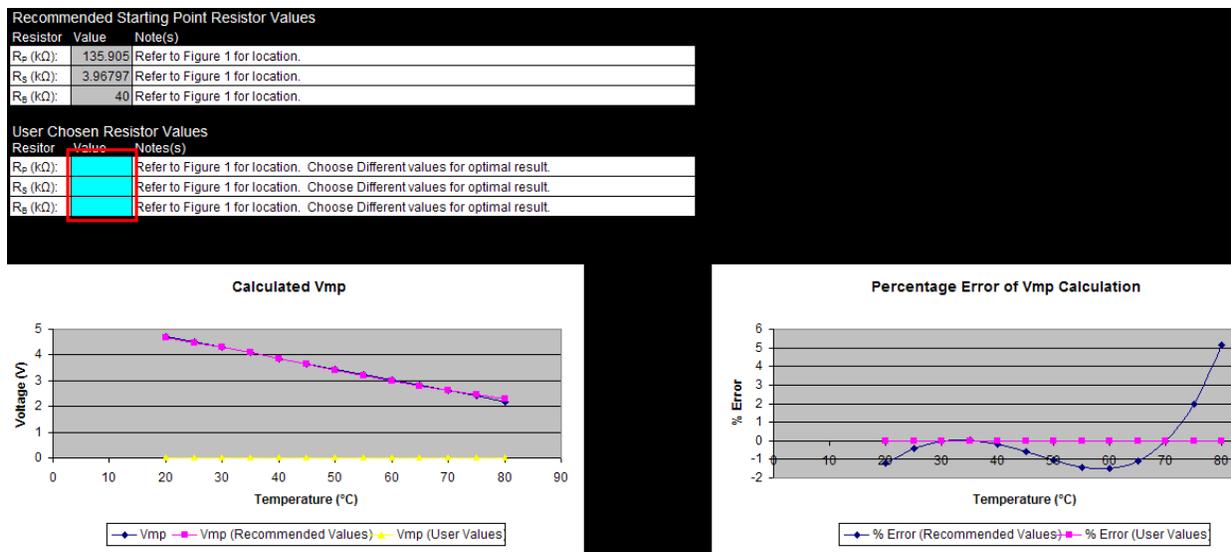


Figure 12. Initial State of Graphs

Once the user enters values for the resistors, the yellow trace on the Calculated V_{MP} graph change according to those values, and the magenta trace on the Percentage Error of V_{MP} Calculation changes accordingly as well. Figure 13 displays the updated graphs once resistor values have been chosen. For this example, the values chosen are the nearest 1% resistor values based on the recommended resistor values provided.

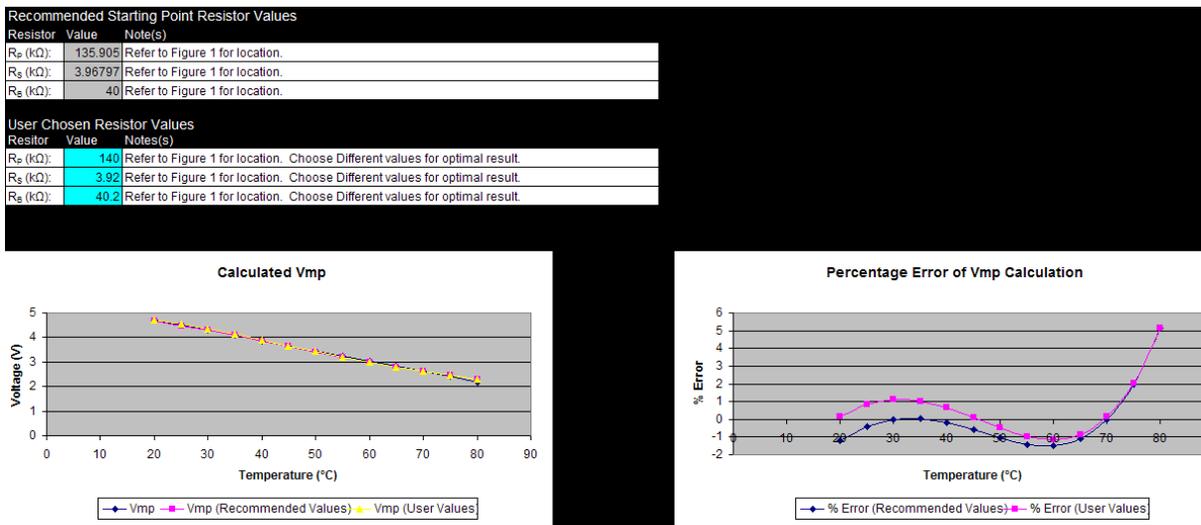


Figure 13. Updated Graphs Based on User-Chosen Resistor Values

The user now has the ability to iterate through various combinations of resistor values in order to try and reduce the error between their calculated V_{MP} over temperature when compared to the solar panel's V_{MP} over temperature. Because of the nonlinearity of the thermistor, it is very difficult to have close to 0% error across the entire temperature range. However, achieving a percentage error of $\pm 3\%$ across the temperature range is plausible. Also, optimizing the error for smaller temperature ranges can be achieved. For instance, even though the entire temperature range in this example is 20°C to 80°C with a maximum error around 5% at 80°C, Figure 13 shows that in the temperature range of 35°C to 55°C the error is within $\pm 1\%$.

Using standard resistor values gathered from using the spreadsheet tool, the bq24650 EVM was modified to incorporate MPP tracking over temperature using the circuit in Figure 4. The solar panel and NTC thermistor mentioned in this example were placed in a temperature chamber so that the temperature of the panel was varied from 20°C to 80°C. With the EVM connected to the solar panel and charging a battery, the result of the V_{MP} change over temperature was recorded and can be seen in Figure 14.

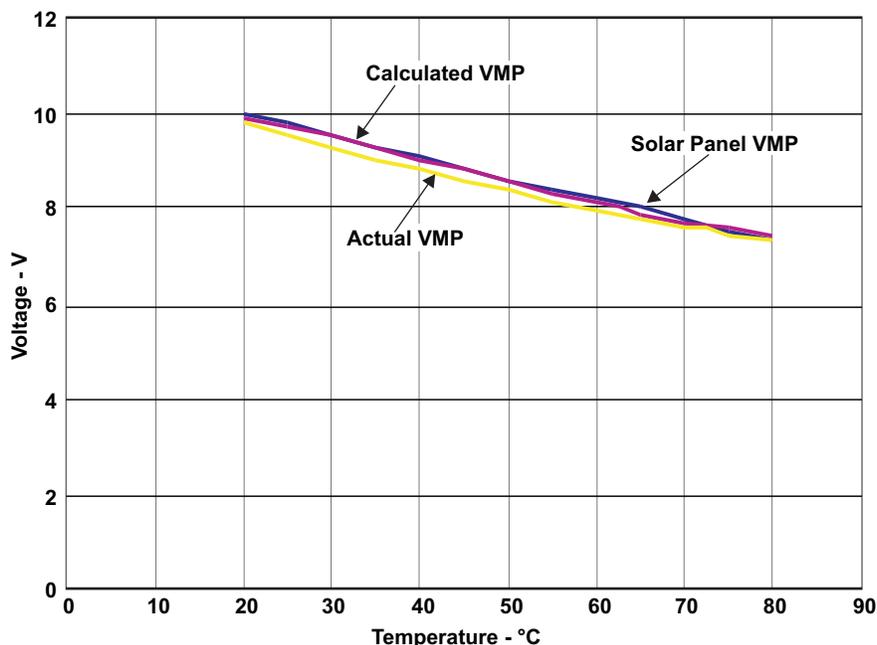


Figure 14. V_{MP} Change Over Temperature Results

The blue trace in [Figure 14](#) represents the change in the V_{MP} value of the solar panel over temperature. This trace can be representative of data sheet information provided by the solar panel's manufacturer. However, in this specific instance, two Sharp LR0GC02 solar panels were connected in series and V_{MP} over temperature data was manually collected. Based on the collected data the V_{MP}/cell , V_{OC}/cell , and temperature coefficient were calculated and entered into the spreadsheet tool. The magenta trace in [Figure 14](#) represents the change in the calculated V_{MP} value over temperature. This data is gathered from the spreadsheet tool, the column labeled Calculated V_{MP} (V) under the Data tab. The yellow trace in [Figure 14](#) represents the actual change in the V_{MP} value over temperature. This data was gathered from the real-world experiment using two Sharp solar panels in series, the previously mentioned NTC thermistor, corresponding R_p , R_s , and R_b values found using the spreadsheet tool and a temperature chamber. As seen in [Figure 14](#), the simple, cost-effective solution provided in this application report, in order to track a solar panel's MPP, proves to be accurate.

4 References

1. *bq24650, Synchronous Switch-Mode Battery Charge Controller for Solar Power with Maximum Power Point Tracking* data sheet ([SLUSA75](#))
2. Sharp Corporation, *Solar Cell Module LR0GC02*, June 2009, <http://www.futureelectronics.com> (September 2010).

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