Generating I-V Curves with the Agilent E4360A Solar Array Simulator Using the Parameters V_{OC}, I_{SC}, N, and R_S

Application Note

Overview

Agilent's family of solar array simulators, including the E435XB Series and E4360A modular solar array simulator mainframe, can be programmed to simulate a wide range of solar array performances. Three methods for generating an I-V curve are available: using table mode to enter I-V data pairs and using parametric values in SAS and list modes.

Two major formats for parametrically programming solar array simulators using equation-based I-V curve generation are currently in use. The parameters required by the equipment using either format are not directly compatible with the other, and the conversion from one format to the other is not mathematically tenable since no closed-form solutions for the equations exist. However, values for V_{OC}, V_{mp}, I_{mp}, and I_{SC}, the Agilent format, can be obtained from the values for V_{OC}, I_{SC}, N, and R_S through the application of an iterative solution technique. This application note provides the methodology.

Parametric Equations

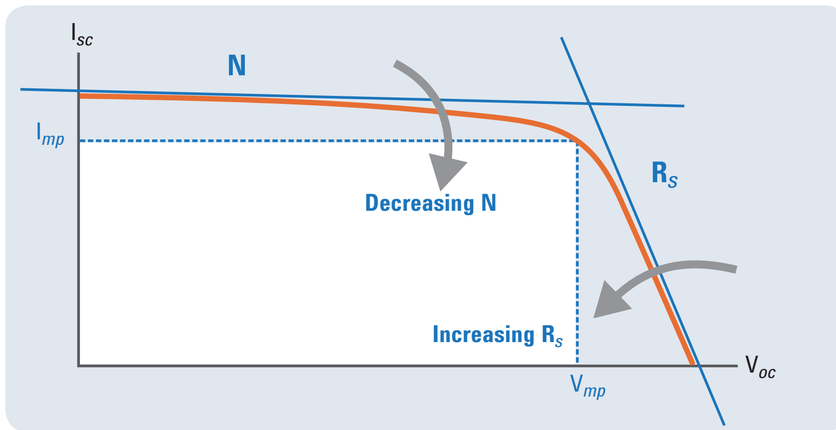
Both parametric formats require the entry of values for the open circuit voltage, V_{oc}, and the short circuit current, I_{sc}. The additional parameters required by the Agilent E435XB series or E4360A are the maximum power point voltage, V_{mp}, and the maximum power point current, I_{mp}. Additional parameters required by the other format are values for N, which is strongly related to the array shunt resistance, and R_s, which is essentially the output resistance of the array.

In Figure 1, the slope of the "horizontal" part of the I-V curve is a strong function of N, and the "vertical" section is a strong function of R_s. Iteratively calculable values of I_{mp} and V_{mp} are a function of N and R_s and will generate an identical I-V curve.

FIGURE 1.

Array I-V curve relationship of R_s, N, and I_{mp}, V_{mp}.

Decreasing N and increasing R_s results in decreasing I_{mp} and V_{mp}.



In SAS and List modes the E4360A accepts four parameters, V_{oc}, V_{mp}, I_{mp}, and I_{sc}, that are applied to internal equations to simulate an I-V curve. The equations are:

EQUATION 1*

$$V = \frac{\dfrac{V_{oc} * \ln\left[2 - \left(\dfrac{I}{I_{sc}}\right)^{N}\right]}{\ln(2)} - R_s * (I - I_{sc})}{\left(1 + \dfrac{R_s * I_{sc}}{V_{oc}}\right)}$$

The exponential model is described in the paper: Britton, Lunscher, and Tanju, "A 9KW High-Performance Solar Array Simulator", Proceedings of the European Space Power Conference, August 1993 (ESA WPP-054, August 1993)

Values for R_s and N are derived from the following:

EQUATION 2

$$R_s = \frac{V_{oc} - V_{mp}}{I_{mp}}$$

EQUATION 3

$$N = \frac{\ln(2 - 2^{a})}{\ln\left(\dfrac{I_{mp}}{I_{sc}}\right)}$$

EQUATION 4

$$a = \frac{V_{mp} * \left(1 + R_s * \dfrac{I_{sc}}{V_{oc}}\right) + R_s * \left(I_{mp} - I_{sc}\right)}{V_{oc}}$$

Problem

Values for V_{mp} and I_{mp} are not directly calculable with the governing transcendental equations. If you are familiar with the parameters V_{oc}, I_{sc}, R_s, and N and prefer to start with them when you work with your Agilent E435XB Series solar array simulator or E4360A solar array simulator system, you must have an accurate, convenient, and fast conversion method. You must be able to obtain values for V_{mp} and I_{mp} that when coupled with V_{oc} and I_{sc} result in I-V curves that are identical to those generated by the N and R_s format.

Solution

Obtaining values for V_{mp} and I_{mp} begins with manipulating equations 2 and 4 to obtain a new expression for equation 4 that replaces V_{mp} with I_{mp}. That is accomplished by substituting for the variable V_{mp} in equation 4 with the expression for V_{mp} derived from equation 2. The equation for N is then iteratively solved until its calculated value equals the value of N given as a part of the V_{oc}, I_{sc}, R_s and N parameter list. Starting with an initial value for I_{mp} and then incrementing I_{mp} positively or negatively until the calculated value for N equals the given value of N establishes I_{mp}. V_{mp} may then be calculated with equation 2. The process can of course be done manually, but can be very time consuming. Achieving quick and accurate results can be done with a computer program or a spreadsheet-embedded macro.

Process

Solving equation 2 for V_{mp} results in:

EQUATION 5

$$V_{mp} = V_{oc} - R_s * I_{mp}$$

Substituting equation 5 in the equation for a (equation 4) results in equation 6.

EQUATION 6

$$a = \frac{\left(V_{oc} - R_s * I_{mp}\right) * \left(1 + R_s * \frac{I_{sc}}{V_{oc}}\right) + R_s * \left(I_{mp} - I_{sc}\right)}{V_{oc}}$$

Given V_{oc}, I_{sc}, R_s, and N, equations 6 and 3 are iteratively solved for a and N respectively with an initial value for I_{mp} (equal to one half of I_{sc}) that is thereafter incremented (increased and/or decreased) until the calculated value for N is within an acceptable error band relative to the given value of N. The magnitude of the error band determines the degree to which the calculated values of V_{mp} and I_{mp} will result in an equivalent curve generated by the R_s and N values. The magnitude of the error band influences the number of iterations required to establish a value for I_{mp}. The tighter the error band the better the curve match and the greater the number of required iterations.

The calculation of the value of a is maintained as an intermediate step as it must be checked to ensure that it is not greater than or equal to 1, or less than or equal to zero before calculating the value of N. A value of 1 would result in an attempt to calculate the natural log of zero in equation 3; a calculated solution for N does not exist. Values for a less than or equal to zero or greater than 1 will result in useless calculated values for N.

Conversion Algorithm

An example algorithm follows.

Set allowable error limit for exit criteria. This establishes the allowable error limit for the calculated value of N relative to the given value of N.

```
N_error = N_given*1E-12
```

Set values for calculating initial Imp

```
left = 0
right = Isc
```

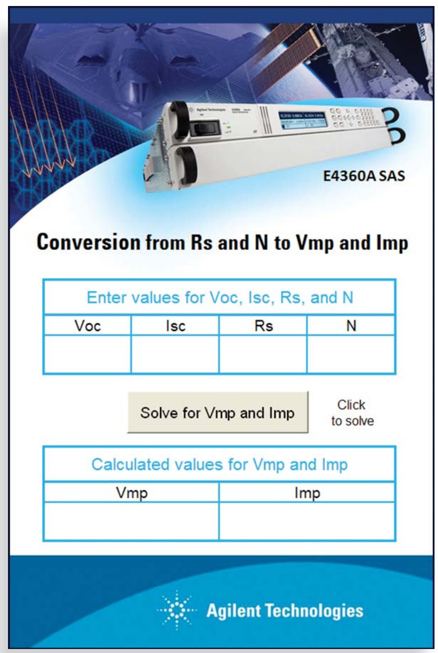
Execute the following loop until the calculated value for N defined as N_calc is within the error limit N_error or until a <= 0 or a =>1.

```
Do
    Imp = (left + right) / 2
    a = ((Voc - Rs * Imp) * (1 + Rs * Isc / Voc) + Rs * (Imp - Isc)) / Voc
    If a <> 1 Then
        N_calc = Log(2 - 2 ^ a) / Log(Imp / Isc)
        If N_calc > N_given Then
            right = Imp
        ElseIf N_calc < N_given Then
            left = Imp
        End If
    End If
Loop Until Abs(N_calc – N_given) <= N_error Or a >= 1 Or a <= 0

If a > 0 And a < 1 And Abs(N_calc – N_given) <= N_error Then

    Vmp = Voc - Rs * Imp

    If the do loop is exited here, the calculated value for Imp is used to
    calculate Vmp. Imp and Vmp are now established

Else

    If the do loop is exited here with a not greater than zero or less than
    1, Vmp and Imp are not calculable with this algorithm.

End If
```

Additional Resources

An R_S and N to V_{mp} and I_{mp} macro embedded spreadsheet conversion tool is available. The following graphic is an illustration of the "Conversion from R_S and N to V_{mp} and I_{mp}" tool available on the Agilent application note Web site. Entering values for V_{OC}, I_{SC}, R_S, and N in the spreadsheet and clicking the Solve for V_{mp} and I_{mp} button will calculate and return values in the designated fields.

To ensure that the values of I_{mp} and V_{mp} will accurately reproduce and represent the I-V curve that would be generated by the use of R_S and N, the maximum allowable error in the calculation of N is limited to 1e-12 times the given value of N.



Related Agilent Literature

Publication	Publication type	Literature number
Conversion from Rs and N to Vmp and Imp Download from: www.agilent.com/find/E4360Conversion	Spread sheet	NA
Agilent E4360 Modular Solar Array Simulators	Data sheet	5989-8485EN
Side-by-Side Comparison of Agilent E435xB and E436xA Solar Array Simulators	Application note	5989-9884EN

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