

A1
 Confronto Koe et al - Kyocera KC175 - GHT2

Voc := 29.2

Isc := 8.09

Vmp := 23.6

Imp := 7.42

$\alpha := -1.09 \cdot 10^{-1}$

$\beta := 3.18 \cdot 10^{-3}$

Ns := 48

Eq := 1.21

T := 298

IL := Isc

$$a = \frac{\alpha T - Voc + Eq Ns}{\frac{T \beta}{IL} - 3}$$

$$I0 = \frac{IL}{e^{\frac{Voc}{a}} - 1}$$

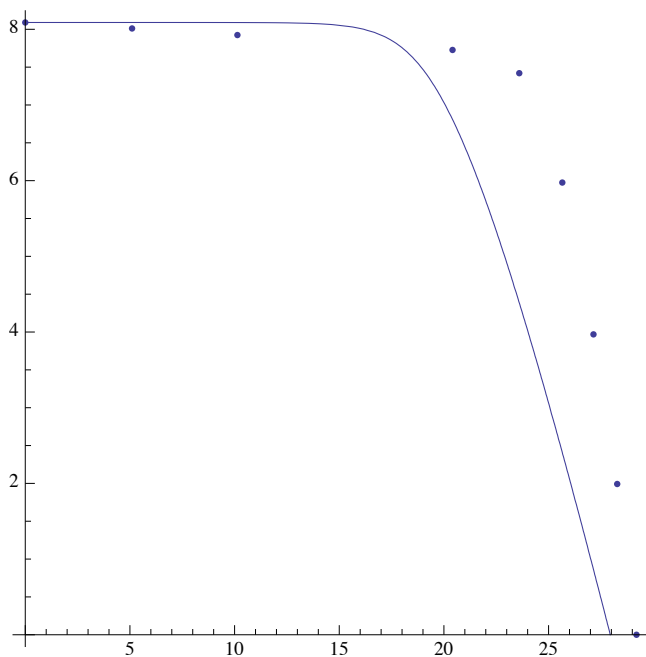
$$Rs = \frac{a \left(1 - \frac{Imp}{IL}\right) - Vmp + Voc}{Imp}$$

Show[ListPlot[{{0, 8.09}, {5.102, 8.011}, {10.135, 7.924}, {20.412, 7.727},
 {23.6, 7.42}, {25.656, 5.975}, {27.145, 3.969}, {28.279, 1.992}, {29.2, 0}}],
 ContourPlot[Isc - I0 (e ^{$\frac{x+Rs y}{a}$} - 1) - y == 0, {x, 0, Voc}, {y, 0, Isc}], AspectRatio -> 1 / 1]

1.24945

1.5584×10^{-9}

0.768663



Confronto Koe et al - Sanyo HIP180 - BA19

Voc := 66.4

Isc := 3.65

Vmp := 54

Imp := 3.33

α := -0.173

β := $1.10 \cdot 10^{-3}$

Ns := 96

Eq := 1.21

T := 298

IL := Isc

$$a = \frac{\alpha T - Voc + Eq Ns}{\frac{T\beta}{IL} - 3}$$

$$I0 = \frac{IL}{e^{\frac{Voc}{a}} - 1}$$

$$Rs = \frac{a \left(1 - \frac{Imp}{IL}\right) - Vmp + Voc}{Imp}$$

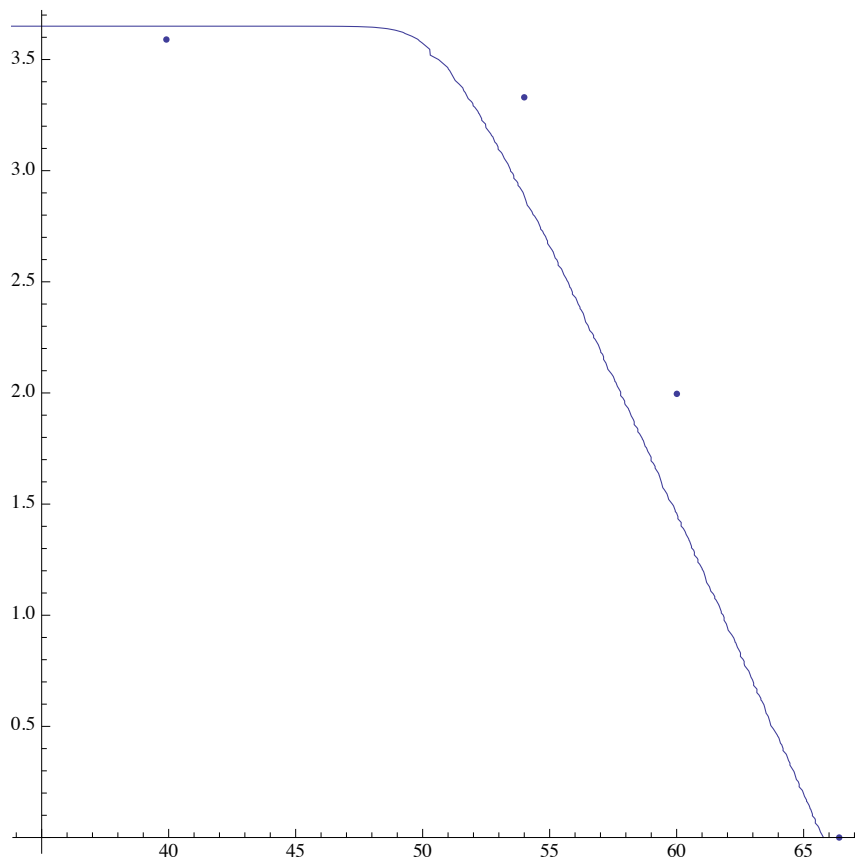
Show[ListPlot[{{0, Isc}, {39.91, 3.59}, {Vmp, Imp}, {60.008, 1.996}, {Voc, 0}}],

ContourPlot[Isc - I0 $\left(e^{\frac{x+Rs y}{a}} - 1\right) - y = 0$, {x, 0, Voc}, {y, 0, Isc}], AspectRatio -> 1 / 1]

0.6164542185234735`

1.650135794715878`*^-46

3.739953543948951`



Confronto Koe et al - Sharp NT - 175 (E1)

Voc := 44.4

Isc := 5.4

Vmp := 35.4

Imp := 4.95

$\alpha := -156 \cdot 10^{-3}$

$\beta := 0.053 \cdot 10^{-2}$

Ns := 72

Eq := 1.21

T := 298

IL := Isc

$$a = \frac{\alpha T - Voc + Eq Ns}{\frac{T \beta}{IL} - 3}$$

$$IO = \frac{IL}{e^{\frac{Voc}{a}} - 1}$$

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

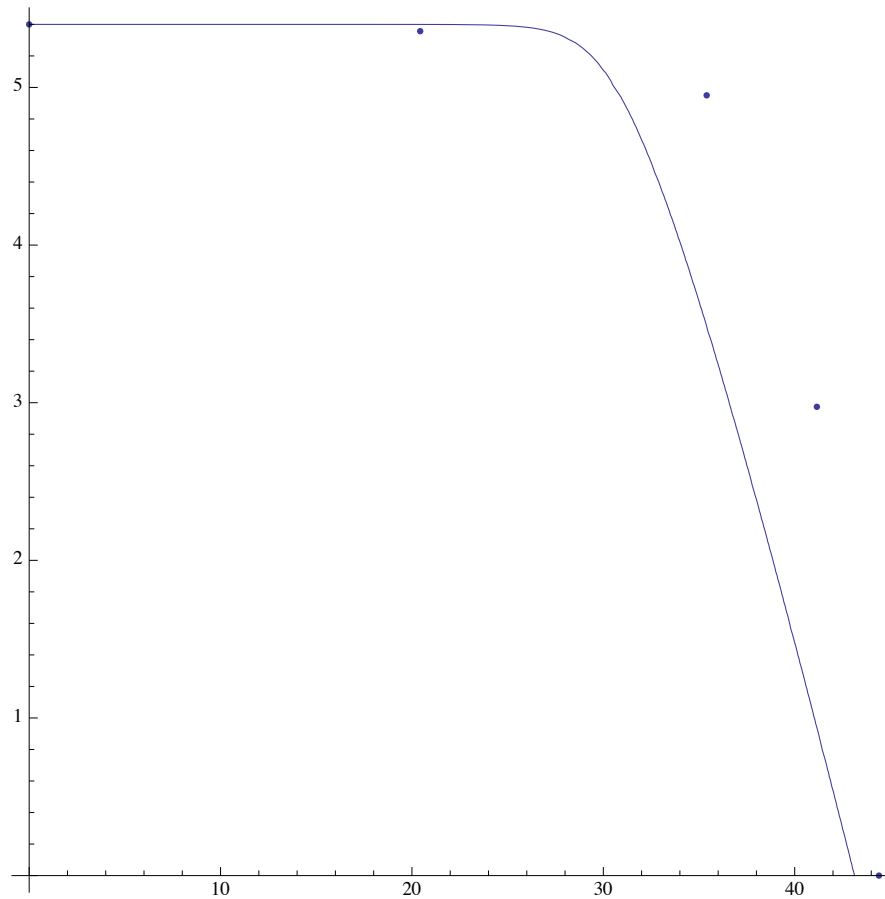
```
Show[ListPlot[{{0, Isc}, {20.431, 5.357}, {Vmp, Imp}, {41.158, 2.974}, {Voc, 0}}],
```

```
ContourPlot[Isc - I0 (e^{\frac{x+R_s y}{a}} - 1) - y == 0, {x, 0, Voc}, {y, 0, Isc}], AspectRatio -> 1 / 1]
```

```
1.2683657834467645`
```

```
9.202734434682184`*^-15
```

```
1.8395347774991038`
```



Confronto Celik et al. - Kyocera KC175 - GHT2

Voc := 29.2

Isc := 8.09

Vmp := 23.6

Imp := 7.42

Rso = 0.42

Rsho = 99.44

T = 298

Rsh := Rsho

$$Vt = \frac{1.380658 \cdot 10^{-23} \cdot T}{1.6021773 \cdot 10^{-19}}$$

$$m = (Vmp + Imp \cdot Rso - Voc) / \left(Vt \left(\log \left[Isc - \frac{Vmp}{Rsho} - Imp \right] - \log \left[Isc - \frac{Voc}{Rsho} \right] + \frac{Imp}{Isc - \frac{Voc}{Rsho}} \right) \right)$$

$$Rs = Rso - \frac{m \cdot Vt}{\left(Isc - \frac{Voc}{Rsho} \right)}$$

$$I0 := \left(Isc - \frac{Voc}{Rsho} \right) e^{\left(\frac{-Voc}{m \cdot Vt} \right)}$$

$$IL := Isc \left(1 + \frac{Rs}{Rsho} \right) + I0 \left(e^{\frac{Isc \cdot Rs}{m \cdot Vt}} - 1 \right)$$

$$\text{FindRoot} \left[IL - I0 \left(e^{\frac{0 + Rs \cdot y}{m \cdot Vt}} - 1 \right) - \frac{0 + Rs \cdot y}{Rsh} - y == 0, \{y, 9\} \right]$$

$$\text{FindRoot} \left[IL - I0 \left(e^{\frac{29.2 + Rs \cdot y}{m \cdot Vt}} - 1 \right) - \frac{29.2 + Rs \cdot y}{Rsh} - y == 0, \{y, 0\} \right]$$

$$\text{FindRoot} \left[IL - I0 \left(e^{\frac{23.6 + Rs \cdot y}{m \cdot Vt}} - 1 \right) - \frac{23.6 + Rs \cdot y}{Rsh} - y == 0, \{y, 7.5\} \right]$$

$$\text{FindRoot} \left[IL - I0 \left(e^{\frac{5.102 + Rs \cdot y}{m \cdot Vt}} - 1 \right) - \frac{5.102 + Rs \cdot y}{Rsh} - y == 0, \{y, 7.5\} \right]$$

Show[ListPlot[{{0, 8.09}, {5.102, 8.011}, {10.135, 7.924}, {20.412, 7.727},
{23.6, 7.42}, {25.656, 5.975}, {27.145, 3.969}, {28.279, 1.992}, {29.2, 0}}],

ContourPlot[IL - I0 (e^{(x+Rs y)/(m Vt)} - 1) - (x + Rs y)/Rsho - y == 0, {x, 0, Voc}, {y, 0, Isc}]]

0.42

99.44

298

0.0256798

49.8602

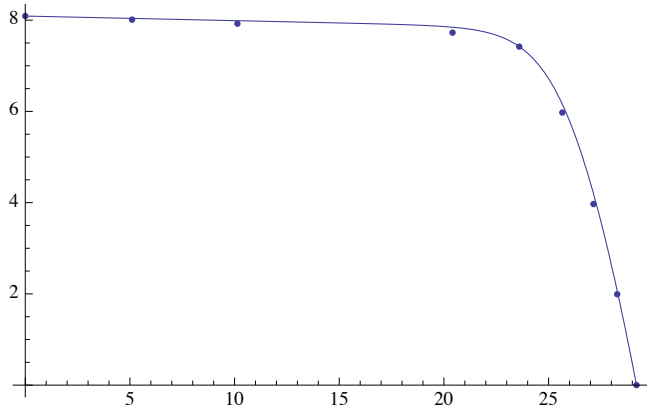
0.25577

{y → 8.09}

{y → 0.00812437}

{y → 7.42158}

{y → 8.03882}



Confronto Celik et al. - Sanyo HIP180 - BA19

Voc := 66.4

Isc := 3.65

Vmp := 54

Imp := 3.33

Rso := 2.9

Rsho := 3920

T := 298

Rsh := Rsho

$$Vt := \frac{1.380658 \cdot 10^{-23} T}{1.6021773 \cdot 10^{-19}}$$

$$m := (Vmp + Imp Rso - Voc) / \left(Vt \left(\log \left[Isc - \frac{Vmp}{Rsho} - Imp \right] - \log \left[Isc - \frac{Voc}{Rsho} \right] + \frac{Imp}{Isc - \frac{Voc}{Rsho}} \right) \right)$$

$$Rs = Rso - \frac{m Vt}{\left(Isc - \frac{Voc}{Rsho} \right)}$$

$$I0 = \left(Isc - \frac{Voc}{Rsho} \right) e^{\left(\frac{-Voc}{m Vt} \right)}$$

$$IL = Isc \left(1 + \frac{Rs}{Rsho} \right) + I0 \left(e^{\frac{Isc Rs}{m Vt}} - 1 \right)$$

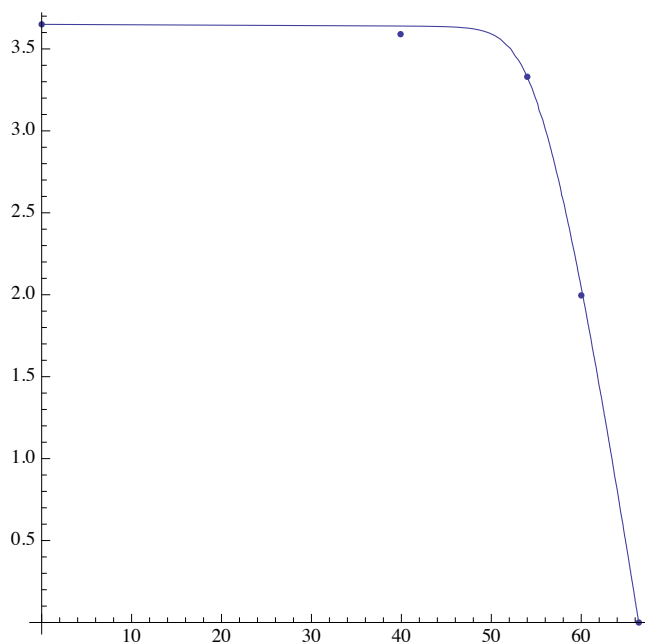
Show[ListPlot[{{0, 3.65}, {39.91, 3.59}, {54, 3.33}, {60.008, 1.996}, {66.4, 0}}],

ContourPlot[IL - I0 (e ^{$\frac{x+Rs y}{m Vt}$} - 1) - $\frac{x + Rs y}{Rsho}$ - y == 0, {x, 0, Voc}, {y, 0, Isc}], AspectRatio -> 1 / 1]

2.41506

1.55694 × 10⁻¹⁶

3.65225



Confronto Celik et al. - Sharp NT - 175 (E1)

Voc := 44.4

Isc := 5.4

Vmp := 35.4

Imp := 4.95

Rso = 1

Rsho = 90

T = 298

Rsh := Rsho

$$Vt = \frac{1.380658 \cdot 10^{-23} T}{1.6021773 \cdot 10^{-19}}$$

$$m = (Vmp + Imp Rso - Voc) / \left(Vt \left(\log \left[Isc - \frac{Vmp}{Rsho} - Imp \right] - \log \left[Isc - \frac{Voc}{Rsho} \right] + \frac{Imp}{Isc - \frac{Voc}{Rsho}} \right) \right)$$

m Vt

$$Rs = Rso - \frac{m Vt}{\left(Isc - \frac{Voc}{Rsho} \right)}$$

$$I0 = \left(Isc - \frac{Voc}{Rsho} \right) e^{\left(\frac{-Voc}{m Vt} \right)}$$

$$IL = Isc \left(1 + \frac{Rs}{Rsho} \right) + I0 \left(e^{\frac{Isc Rs}{m Vt}} - 1 \right)$$

Show[ListPlot[{{0, Isc}, {20.431, 5.357}, {Vmp, Imp}, {41.158, 2.974}, {Voc, 0}}],

ContourPlot[IL - I0 (e ^{$\frac{x+Rs y}{m Vt}$} - 1) - $\frac{x + Rs y}{Rsho}$ - y == 0, {x, 0, Voc}, {y, 0, Isc}], AspectRatio -> 1 / 1]

1

90

298

0.0256798

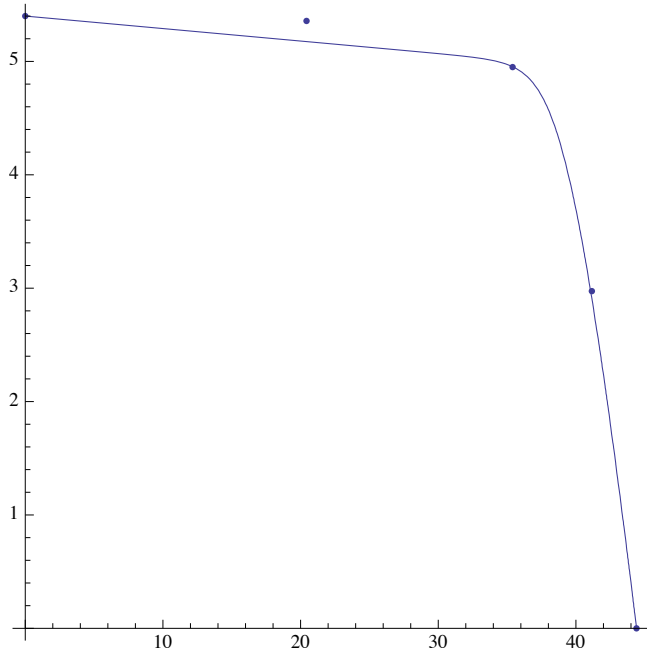
45.6826

1.17312

0.760913

1.79349 × 10⁻¹⁶

5.44565



Cnfronto Celik et al. - Costruttore QCells Q6LMX3

Voc := 0.608

Isc := 7.665

Vmp := 0.513

Imp := 7.174

Rso := 0.00443

Rsho := 9.967

T := 298

Rsh := Rsho

$$Vt := \frac{1.380658 \cdot 10^{-23} T}{1.6021773 \cdot 10^{-19}}$$

$$m := (Vmp + Imp Rso - Voc) / \left(Vt \left(\log \left[Isc - \frac{Vmp}{Rsho} - Imp \right] - \log \left[Isc - \frac{Voc}{Rsho} \right] + \frac{Imp}{Isc - \frac{Voc}{Rsho}} \right) \right)$$

$$Rs = Rso - \frac{m Vt}{\left(Isc - \frac{Voc}{Rsho} \right)}$$

$$I0 = \left(Isc - \frac{Voc}{Rsho} \right) e^{\left(\frac{-Voc}{m Vt} \right)}$$

$$IL = Isc \left(1 + \frac{Rs}{Rsho} \right) + I0 \left(e^{\frac{Isc Rs}{m Vt}} - 1 \right)$$

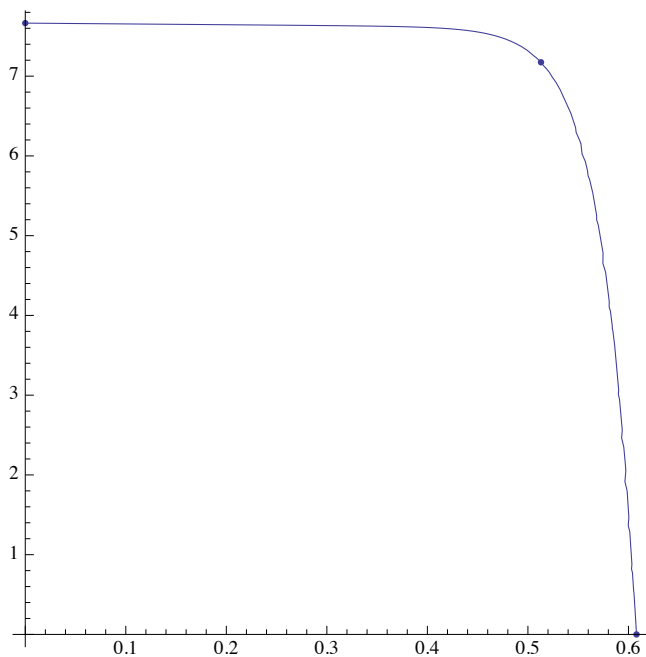
Show[ListPlot[{{0, Isc}, {Vmp, Imp}, {Vs, Is}], {Vocr, 0}],

ContourPlot[IL - I0 (e^{\frac{x+Rs y}{m Vt}} - 1) - \frac{x + Rs y}{Rsho} - y == 0, {x, 0, Voc}, {y, 0, Isc}], AspectRatio -> 1 / 1]

0.0000709271

8.21926 × 10⁻⁸

7.66505



A2

Applicazione della soluzione analitica del modello equivalente a quattro parametri della cella fotovoltaica al pannello Kyocera KC175 - GHT2

Voc := 29.2
Isc := 8.09
Vmp := 23.6
Imp := 7.42

$$\text{ContourPlot}\left[\left\{\left\{e^{\frac{Vmp+Rs\ Imp-Voc}{nTc}} - \frac{nTc}{Vmp - Rs\ Imp + nTc} = 0, \frac{Vmp - Rs\ Imp + nTc}{Vmp - Rs\ Imp} \left(1 - e^{\frac{Rs\ Isc-Voc}{nTc}}\right) - \frac{Isc}{Imp} = 0\right\}, \{Rs, 0, 4\}, \{nTc, 0, 2.5\}\right]$$

$$\text{ans} = \{Rs, nTc\} /. \text{FindRoot}\left[\left\{e^{\frac{Vmp+Rs\ Imp-Voc}{nTc}} - \frac{nTc}{Vmp - Rs\ Imp + nTc} = 0, \frac{Vmp - Rs\ Imp + nTc}{Vmp - Rs\ Imp} \left(1 - e^{\frac{Rs\ Isc-Voc}{nTc}}\right) - \frac{Isc}{Imp} = 0\right\}, \{\{Rs, 0\}, \{nTc, 1.5\}\}\right]$$

Rs = Extract[ans, 1]

nTc = Extract[ans, 2]

$$Roc = \frac{nTc}{Isc} \left(1 - e^{\frac{Rs\ Isc-Voc}{nTc}}\right) + Rs$$

$$Rsc = \frac{nTc}{Isc} \left(e^{\frac{Rs\ Isc-Voc}{nTc}} - 1\right) + Rs$$

$$IO = \frac{nTc}{Roc - Rs} e^{\frac{-Voc}{nTc}}$$

$$Iph = \frac{nTc}{Roc - Rs} - IO$$

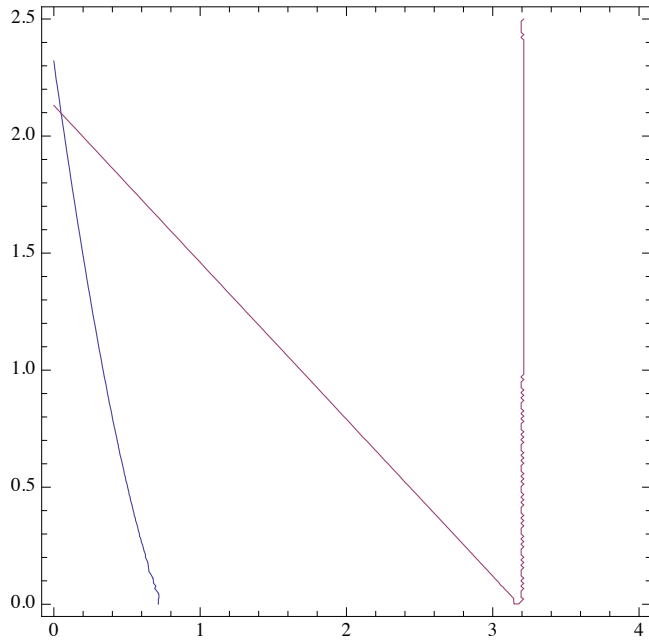
$$\text{FindRoot}\left[Iph - IO \left(e^{\frac{0+Rs\ y}{nTc}} - 1\right) - y = 0, \{y, 1\}\right]$$

$$\text{FindRoot}\left[Iph - IO \left(e^{\frac{29.2+Rs\ y}{nTc}} - 1\right) - y = 0, \{y, 0\}\right]$$

$$\text{FindRoot}\left[Iph - IO \left(e^{\frac{23.6+Rs\ y}{nTc}} - 1\right) - y = 0, \{y, 7\}\right]$$

Show[ListPlot[{{0, 8.09}, {5.102, 8.011}, {10.135, 7.924}, {20.412, 7.727}, {23.6, 7.42}, {25.656, 5.975}, {27.145, 3.969}, {28.279, 1.992}, {29.2, 0}],

ContourPlot[Iph - IO (e ^{$\frac{x+Rs\ y}{nTc}$} - 1) - y = 0, {x, 0, 30}, {y, 0, 10}]]



{0.0506725, 2.09707}

0.0506725

2.09707

0.30989

237 659.

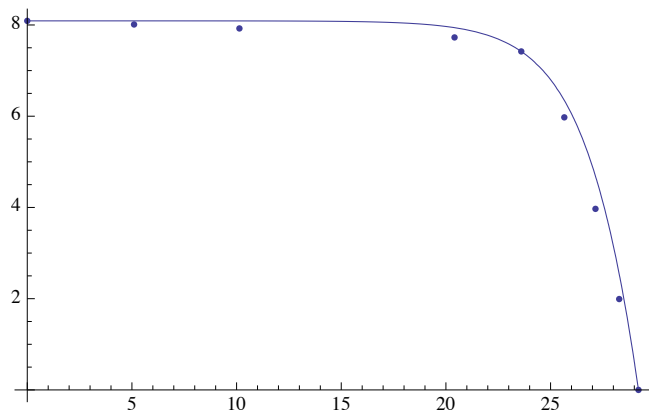
7.25709×10^{-6}

8.09

{149.949 → 8.09}

{149.949 → 0.}

{149.949 → 7.42}



Applicazione della soluzione analitica del modello equivalente a quattro parametri della cella fotovoltaica al pannello Sanyo HIP180 - BA19

Voc := 66.4
 Isc := 3.65
 Vmp := 54
 Imp := 3.33

ContourPlot $\left[\left\{ e^{\frac{Vmp+Rs Imp-Voc}{nTc}} - \frac{nTc}{Vmp-Rs Imp+nTc}, \frac{Vmp-Rs Imp+nTc}{Vmp-Rs Imp} \left(1 - e^{\frac{Rs Isc-Voc}{nTc}} \right) - \frac{Isc}{Imp} \right\}, \{Rs, -1, 100\}, \{nTc, -1, 100\} \right]$

ans = {Rs, nTc} /. FindRoot $\left[\left\{ e^{\frac{Vmp+Rs Imp-Voc}{nTc}} - \frac{nTc}{Vmp-Rs Imp+nTc} == 0, \frac{Vmp-Rs Imp+nTc}{Vmp-Rs Imp} \left(1 - e^{\frac{Rs Isc-Voc}{nTc}} \right) - \frac{Isc}{Imp} == 0 \right\}, \{Rs, 0\}, \{nTc, 1.5\} \right]$

Rs = Extract[ans, 1]

nTc = Extract[ans, 2]

Roc = $\frac{nTc}{Isc} \left(1 - e^{\frac{Rs Isc-Voc}{nTc}} \right) + Rs$

Rsc = $\frac{nTc}{Isc} \left(e^{-\frac{Rs Isc-Voc}{nTc}} - 1 \right) + Rs$

I0 = $\frac{nTc}{Roc-Rs} e^{-\frac{Voc}{nTc}}$

Iph = $\frac{nTc}{Roc-Rs} - I0$

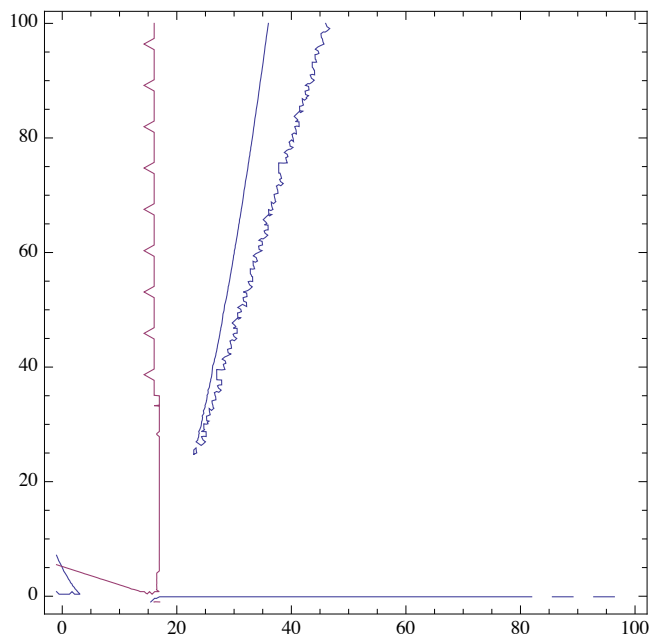
FindRoot $\left[Iph - I0 \left(e^{\frac{0+Rs y}{nTc}} - 1 \right) - y == 0, \{y, 1\} \right]$

FindRoot $\left[Iph - I0 \left(e^{\frac{Voc+Rs y}{nTc}} - 1 \right) - y == 0, \{y, 0\} \right]$

FindRoot $\left[Iph - I0 \left(e^{\frac{Vmp+Rs y}{nTc}} - 1 \right) - y == 0, \{y, 7\} \right]$

Show[ListPlot[{{0, 3.65}, {39.91, 3.59}, {54, 3.33}, {60.008, 1.996}, {66.4, 0}}],

ContourPlot $\left[Iph - I0 \left(e^{\frac{x+Rs y}{nTc}} - 1 \right) - y == 0, \{x, 0, 65\}, \{y, 0, 10\} \right]$



$\{-0.0907767, 5.2184\}$

-0.0907767

5.2184

1.33892

511525.

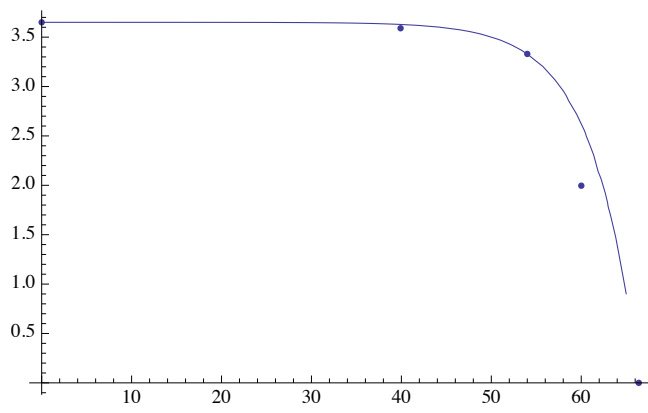
0.0000108704

3.65

$\{y \rightarrow 3.65\}$

$\{y \rightarrow 0.\}$

$\{y \rightarrow 3.33\}$



Applicazione della soluzione analitica del modello equivalente a quattro parametri della cella fotovoltaica al pannello Sharp NT - 175 (E1)

Voc := 44.4
 Isc := 5.4
 Vmp := 35.4
 Imp := 4.95

$$\text{ans} = \{Rs, nTc\} /. \text{FindRoot} \left[\left\{ e^{\frac{Vmp+Rs \cdot Imp-Voc}{nTc}} - \frac{nTc}{Vmp - Rs \cdot Imp + nTc} = 0, \right. \right. \\ \left. \left. \frac{Vmp - Rs \cdot Imp + nTc}{Vmp - Rs \cdot Imp} \left(1 - e^{\frac{Rs \cdot Isc - Voc}{nTc}} \right) - \frac{Isc}{Imp} = 0 \right\}, \{\{Rs, 0\}, \{nTc, 1.5\}\} \right]$$

Rs = Extract[ans, 1]

nTc = Extract[ans, 2]

$$Roc = \frac{nTc}{Isc} \left(1 - e^{\frac{Rs \cdot Isc - Voc}{nTc}} \right) + Rs$$

$$Rsc = \frac{nTc}{Isc} \left(e^{-\frac{Rs \cdot Isc - Voc}{nTc}} - 1 \right) + Rs$$

$$IO = \frac{nTc}{Roc - Rs} e^{\frac{-Voc}{nTc}}$$

$$Iph = \frac{nTc}{Roc - Rs} - IO$$

$$\text{FindRoot} \left[Iph - IO \left(e^{\frac{0+Rs \cdot y}{nTc}} - 1 \right) - y = 0, \{y, 1\} \right]$$

$$\text{FindRoot} \left[Iph - IO \left(e^{\frac{Voc+Rs \cdot y}{nTc}} - 1 \right) - y = 0, \{y, 0\} \right]$$

$$\text{FindRoot} \left[Iph - IO \left(e^{\frac{Vmp+Rs \cdot y}{nTc}} - 1 \right) - y = 0, \{y, 7\} \right]$$

Show[ListPlot[{{0, Isc}, {20.431, 5.357}, {Vmp, Imp}, {41.158, 2.974}, {Voc, 0}],

ContourPlot[Iph - IO (e ^{$\frac{x+Rs \cdot y}{nTc}$} - 1) - y = 0, {x, 0, 45}, {y, 0, 6}]]

{0.261774, 3.10042}

0.261774

3.10042

0.835925

603108.

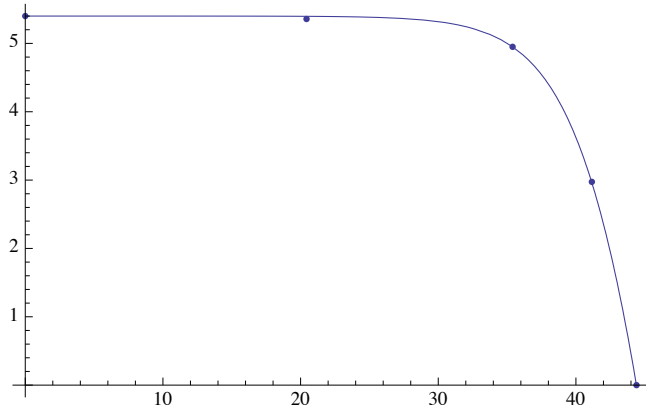
3.25849 × 10⁻⁶

5.4

{y → 5.4}

{y → 0.}

{y → 4.95}



Applicazione della soluzione analitica del modello equivalente a quattro parametri della cella fotovoltaica alla cella QCells Q6LMX3

```
Voc := 0.608
Isc := 8.6
Vmp := 0.5
Imp := 8.29
```

```
ContourPlot [ { { e(Vmp+Rs Imp-Voc)/nTc -  $\frac{nTc}{Vmp - Rs Imp + nTc}$ ,  $\frac{Vmp - Rs Imp + nTc}{Vmp - Rs Imp} \left( 1 - e^{\frac{Rs Isc-Voc}{nTc}} \right) - \frac{Isc}{Imp}$  },
  {Rs, 0, 0.2}, {nTc, 0, 0.1} ]
```

```
ans = {Rs, nTc} /. FindRoot [ { { e(Vmp+Rs Imp-Voc)/nTc -  $\frac{nTc}{Vmp - Rs Imp + nTc}$  == 0,
   $\frac{Vmp - Rs Imp + nTc}{Vmp - Rs Imp} \left( 1 - e^{\frac{Rs Isc-Voc}{nTc}} \right) - \frac{Isc}{Imp} == 0$  }, {{Rs, 0}, {nTc, 0.25}} ]
```

```
Rs = Extract[ans, 1]
```

```
nTc = Extract[ans, 2]
```

```
Roc =  $\frac{nTc}{Isc} \left( 1 - e^{\frac{Rs Isc-Voc}{nTc}} \right) + Rs$ 
```

```
Rsc =  $\frac{nTc}{Isc} \left( e^{-\frac{Rs Isc-Voc}{nTc}} - 1 \right) + Rs$ 
```

```
I0 =  $\frac{nTc}{Roc - Rs} e^{-\frac{Voc}{nTc}}$ 
```

```
Iph =  $\frac{nTc}{Roc - Rs} - I0$ 
```

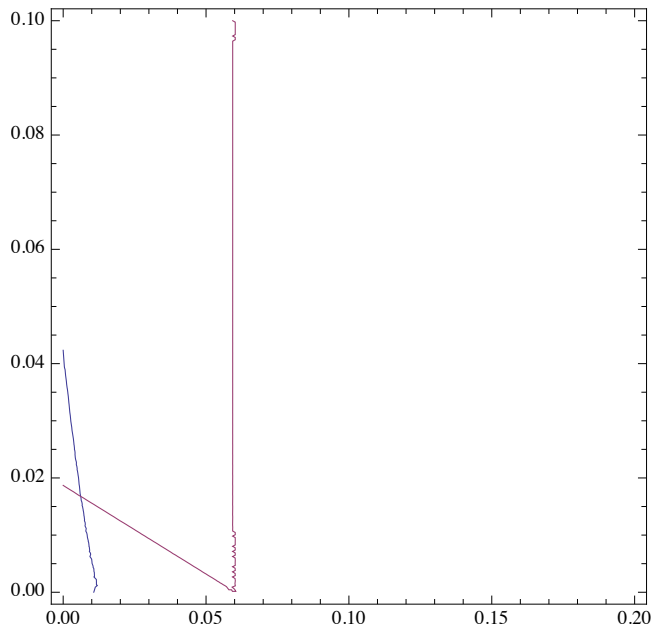
```
FindRoot [ Iph - I0  $\left( e^{\frac{0+Rs y}{nTc}} - 1 \right) - y == 0$ , {y, 1} ]
```

```
FindRoot [ Iph - I0  $\left( e^{\frac{Voc+Rs y}{nTc}} - 1 \right) - y == 0$ , {y, 0} ]
```

```
FindRoot [ Iph - I0  $\left( e^{\frac{Vmp+Rs y}{nTc}} - 1 \right) - y == 0$ , {y, 8} ]
```

```
Show [ ListPlot [ { {0, Isc}, {Vmp, Imp}, {Voc, 0} } ],
```

```
ContourPlot [ Iph - I0  $\left( e^{\frac{x+Rs y}{nTc}} - 1 \right) - y == 0$ , {x, 0, 0.8}, {y, 0, 9} ] ]
```



{0.0063183, 0.0167386}

0.0063183

0.0167386

0.00826464

4.5125×10^{11}

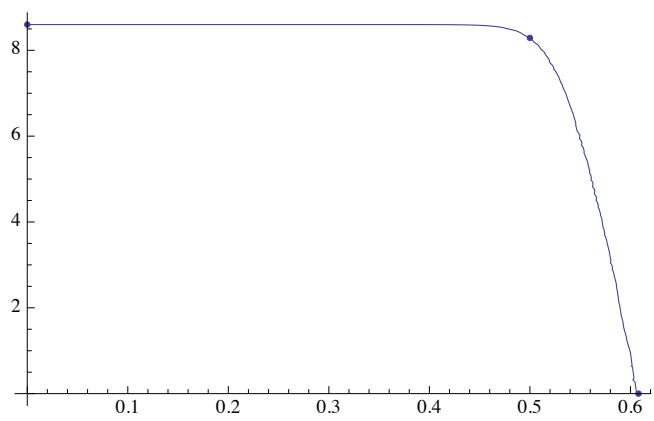
1.4437×10^{-15}

8.6

{y → 8.6}

{y → 0.}

{y → 8.29}



A3

Applicazione della soluzione analitica del modello equivalente a cinque parametri della cella fotovoltaica al pannello Kyocera KC175 - GHT2 STC

Voc := 29.2
 Isc := 8.09
 Vmp := 23.6
 Imp := 7.42
 VM := 5
 IM := 8.011

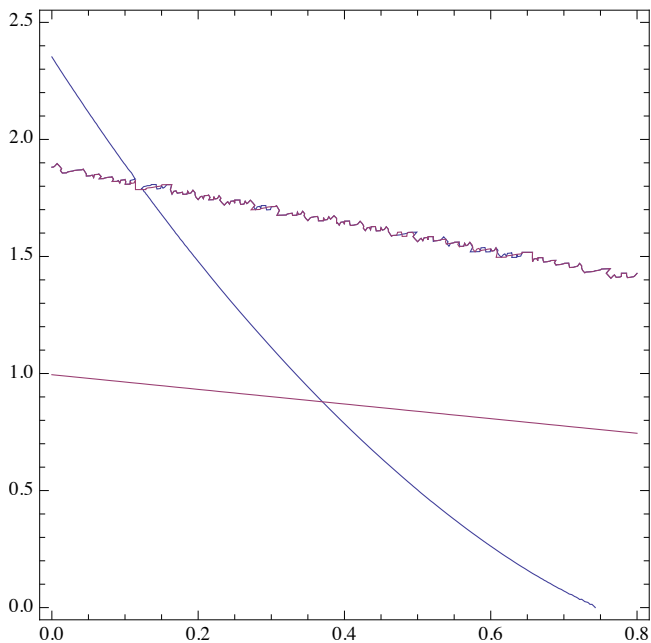
$$Rmp := \frac{Vmp}{Imp}$$

$$Roc := \left(Rs (Rmp - Rs) ((Voc - Vmp) IM - (Voc - VM) Imp) - \right. \\ \left. Rmp nTc ((Voc - VM) - Rs IM) + nTc (Rmp nTc + (Voc - Vmp) (Rmp - Rs)) \left(1 - e^{-\frac{Rs IM - (Voc - VM)}{nTc}} \right) \right) / \\ \left((Rmp - Rs) ((Voc - Vmp) IM - (Voc - VM) Imp) - nTc ((Voc - VM) - Rs IM) + \right. \\ \left. nTc (nTc + (Rmp - Rs) Imp) \left(1 - e^{-\frac{Rs IM - (Voc - VM)}{nTc}} \right) \right)$$

$$Rsc := 1 / ((Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) + \\ nTc ((Rmp - Rs) ((Voc - Vmp) - Rs Imp) - (Voc - Rs Isc) (Rmp - Roc))) \\ (Rs (Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) + \\ nTc (Roc (Rmp - Rs) ((Voc - Vmp) - Rs Imp) - Rs (Voc - Rs Isc) (Rmp - Roc)))$$

$$Rsh := \frac{(Roc - Rs) (Vmp - Rs Imp) ((Voc - Vmp) - Rs Imp)}{(Roc - Rs) (Vmp - Rs Imp) Imp - nTc (Vmp - Roc Imp)}$$

$$\text{ContourPlot} \left[\left\{ \left(\frac{Rsh}{Rmp - Rs} - 1 \right) - \left(\frac{Rsh}{Roc - Rs} - 1 \right) e^{-\frac{Vmp + Rs Imp - Voc}{nTc}} = 0, \right. \right. \\ \left. \left. \left(\frac{Rsh}{Rsc - Rs} - 1 \right) - \left(\frac{Rsh}{Roc - Rs} - 1 \right) e^{-\frac{Rs Isc - Voc}{nTc}} = 0 \right\}, \{Rs, 0, 0.8\}, \{nTc, 0, 2.5\} \right]$$



Voc := 29.2
Isc := 8.09
Vmp := 23.6
Imp := 7.42
VM := 5
IM := 8.011

$$\mathbf{Rmp} := \frac{\mathbf{Vmp}}{\mathbf{Imp}}$$

$$\mathbf{Roc} := \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} := 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$\mathbf{Rsh} := \frac{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Vmp} - \mathbf{Rs} \mathbf{Imp}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp})}{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Vmp} - \mathbf{Rs} \mathbf{Imp}) \mathbf{Imp} - \mathbf{nTc} (\mathbf{Vmp} - \mathbf{Roc} \mathbf{Imp})}$$

$$\mathbf{ans} = \{\mathbf{Rs}, \mathbf{nTc}\} /. \mathbf{FindRoot} \left[\left\{ \left(\frac{\mathbf{Rsh}}{\mathbf{Rmp} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Vmp} + \mathbf{Rs} \mathbf{Imp} - \mathbf{Voc}}{\mathbf{nTc}}} = 0, \right. \right. \\ \left. \left. \left(\frac{\mathbf{Rsh}}{\mathbf{Rsc} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Rs} \mathbf{Isc} - \mathbf{Voc}}{\mathbf{nTc}}} = 0 \right\}, \{\{\mathbf{Rs}, 0.7\}, \{\mathbf{nTc}, 1\}\} \right]$$

Rs = Extract[ans, 1]

nTc = Extract[ans, 2]

$$\mathbf{Roc} = \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} = 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$R_{sh} = \frac{(R_{oc} - R_s) (V_{mp} - R_s I_{mp}) ((V_{oc} - V_{mp}) - R_s I_{mp})}{(R_{oc} - R_s) (V_{mp} - R_s I_{mp}) I_{mp} - nTc (V_{mp} - R_{oc} I_{mp})}$$

$$I_0 = \frac{nTc}{R_{sh}} \frac{R_s + R_{sh} - R_{oc}}{R_{oc} - R_s} e^{-\frac{V_{oc}}{nTc}}$$

$$I_{ph} = \frac{nTc}{R_{sh}} \frac{R_s + R_{sh} - R_{oc}}{R_{oc} - R_s} + \frac{V_{oc}}{R_{sh}} - I_0$$

Rs + Rsh

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{0+R_s y}{nTc}} - 1\right) - \frac{0 + R_s y}{R_{sh}} - y == 0, \{y, 1\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_{oc}+R_s y}{nTc}} - 1\right) - \frac{V_{oc} + R_s y}{R_{sh}} - y == 0, \{y, 0\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_{mp}+R_s y}{nTc}} - 1\right) - \frac{V_{mp} + R_s y}{R_{sh}} - y, \{y, 7\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_M+R_s y}{nTc}} - 1\right) - \frac{V_M + R_s y}{R_{sh}} - y, \{y, 7\}\right]$$

Show[ListPlot[{{0, 8.09}, {5.102, 8.011}, {10.135, 7.924}, {20.412, 7.727},
{23.6, 7.42}, {25.656, 5.975}, {27.145, 3.969}, {28.279, 1.992}, {29.2, 0}]]],

ContourPlot[I_{ph} - I₀ (e ^{$\frac{x+R_s y}{nTc}$} - 1) - $\frac{x + R_s y}{R_{sh}}$ - y == 0, {x, 0, 30}, {y, 0, 9}]]

{0.370141, 0.879225}

0.370141

0.879225

0.484512

63.2911

62.921

2.8948 × 10⁻¹⁴

8.13759

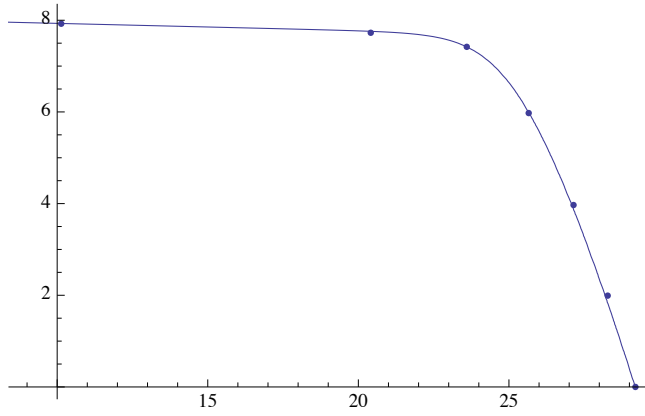
63.2911

{y → 8.09}

{y → 0.}

{y → 7.42}

{y → 8.011}



Applicazione della soluzione analitica del modello equivalente a cinque parametri della cella fotovoltaica al pannello Kyocera KC175 - GHT2 NOCT

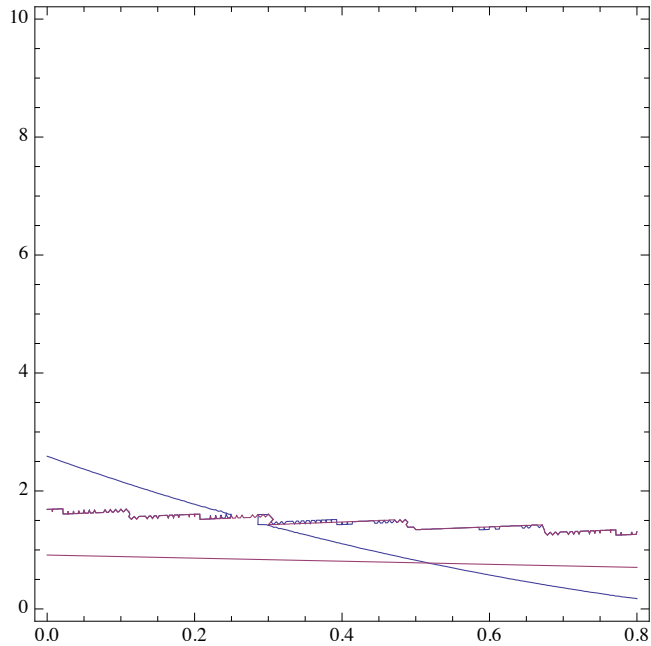
Voc := 26.5
Isc := 6.53
Vmp := 20.9
Imp := 5.99
VM := 4.6
IM := 6.466

$$\mathbf{Rmp} := \frac{\mathbf{Vmp}}{\mathbf{Imp}}$$

$$\mathbf{Roc} := \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{-\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{-\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} := 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$\mathbf{Rsh} := \frac{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp})}{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp} - \mathbf{nTc} (\mathbf{Rmp} - \mathbf{Roc})}$$

$$\mathbf{ContourPlot} \left[\left\{ \left(\frac{\mathbf{Rsh}}{\mathbf{Rmp} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{-\frac{\mathbf{Vmp} + \mathbf{Rs} \mathbf{Imp} - \mathbf{Voc}}{\mathbf{nTc}}} = 0, \right. \right. \\ \left. \left. \left(\frac{\mathbf{Rsh}}{\mathbf{Rsc} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{-\frac{\mathbf{Rs} \mathbf{Isc} - \mathbf{Voc}}{\mathbf{nTc}}} = 0 \right\}, \{ \mathbf{Rs}, 0, 0.8 \}, \{ \mathbf{nTc}, 0, 10 \} \right]$$



Voc := 26.5
Isc := 6.53
Vmp := 20.9
Imp := 5.99
VM := 4.6
IM := 6.466

$$\mathbf{Rmp} := \frac{\mathbf{Vmp}}{\mathbf{Imp}}$$

$$\mathbf{Roc} := \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} := 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$\mathbf{Rsh} := \frac{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp})}{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp} - \mathbf{nTc} (\mathbf{Rmp} - \mathbf{Roc})}$$

$$\mathbf{ans} = \{\mathbf{Rs}, \mathbf{nTc}\} /. \mathbf{FindRoot} \left[\left\{ \left(\frac{\mathbf{Rsh}}{\mathbf{Rmp} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Vmp} + \mathbf{Rs} \mathbf{Imp} - \mathbf{Voc}}{\mathbf{nTc}}} = 0, \right. \right. \\ \left. \left. \left(\frac{\mathbf{Rsh}}{\mathbf{Rsc} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Rs} \mathbf{Isc} - \mathbf{Voc}}{\mathbf{nTc}}} = 0 \right\}, \{\{\mathbf{Rs}, 0.7\}, \{\mathbf{nTc}, 1\}\} \right]$$

Rs = Extract[ans, 1]

nTc = Extract[ans, 2]

$$\mathbf{Roc} = \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} = 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$R_{sh} = \frac{(R_{oc} - R_s) (R_{mp} - R_s) ((V_{oc} - V_{mp}) - R_s I_{mp})}{(R_{oc} - R_s) (R_{mp} - R_s) I_{mp} - nT_c (R_{mp} - R_{oc})}$$

$$I_0 = \frac{nT_c R_s + R_{sh} - R_{oc}}{R_{sh} R_{oc} - R_s} e^{-\frac{V_{oc}}{nT_c}}$$

$$I_{ph} = \frac{nT_c R_s + R_{sh} - R_{oc}}{R_{sh} R_{oc} - R_s} + \frac{V_{oc}}{R_{sh}} - I_0$$

Rs + Rsh

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{0 + R_s y}{nT_c}} - 1\right) - \frac{0 + R_s y}{R_{sh}} - y == 0, \{y, 1\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_{oc} + R_s y}{nT_c}} - 1\right) - \frac{V_{oc} + R_s y}{R_{sh}} - y == 0, \{y, 0\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_{mp} + R_s y}{nT_c}} - 1\right) - \frac{V_{mp} + R_s y}{R_{sh}} - y, \{y, 7\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_M + R_s y}{nT_c}} - 1\right) - \frac{V_M + R_s y}{R_{sh}} - y, \{y, 7\}\right]$$

Show[ListPlot[{{0, 8.09}, {5.102, 8.011}, {10.135, 7.924}, {20.412, 7.727},
{23.6, 7.42}, {25.656, 5.975}, {27.145, 3.969}, {28.279, 1.992}, {29.2, 0}}],

ContourPlot[I_{ph} - I₀ (e ^{$\frac{x + R_s y}{nT_c}$} - 1) - $\frac{x + R_s y}{R_{sh}}$ - y == 0, {x, 0, 30}, {y, 0, 9}]]

{0.518156, 0.778201}

0.518156

0.778201

0.64333

71.875

71.3568

1.00884 × 10⁻¹⁴

6.57742

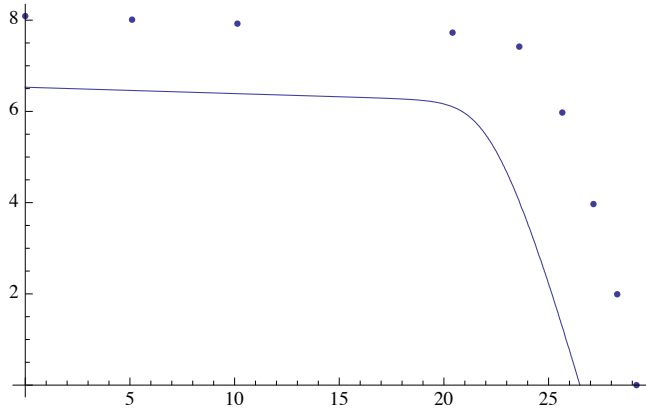
71.875

{y → 6.53}

{y → 0.}

{y → 5.99}

{y → 6.466}



Applicazione della soluzione analitica del modello equivalente a cinque parametri della cella fotovoltaica al pannello Sanyo HIP180 - BA19 STC

$Voc := 66.4$

$Isc := 3.65$

$Vmp := 54$

$Imp := 3.33$

$VM := 19$

$IM := 3.63$

$Rmp := \frac{Vmp}{Imp}$

$Roc := \left(Rs (Rmp - Rs) ((Voc - Vmp) IM - (Voc - VM) Imp) - \right.$

$\left. Rmp nTc ((Voc - VM) - Rs IM) + nTc (Rmp nTc + (Voc - Vmp) (Rmp - Rs)) \left(1 - e^{\frac{Rs IM - (Voc - VM)}{nTc}} \right) \right) /$

$\left((Rmp - Rs) ((Voc - Vmp) IM - (Voc - VM) Imp) - nTc ((Voc - VM) - Rs IM) + \right.$

$\left. nTc (nTc + (Rmp - Rs) Imp) \left(1 - e^{\frac{Rs IM - (Voc - VM)}{nTc}} \right) \right)$

$Rsc := 1 / ((Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) +$

$nTc ((Rmp - Rs) ((Voc - Vmp) - Rs Imp) - (Voc - Rs Isc) (Rmp - Roc))$

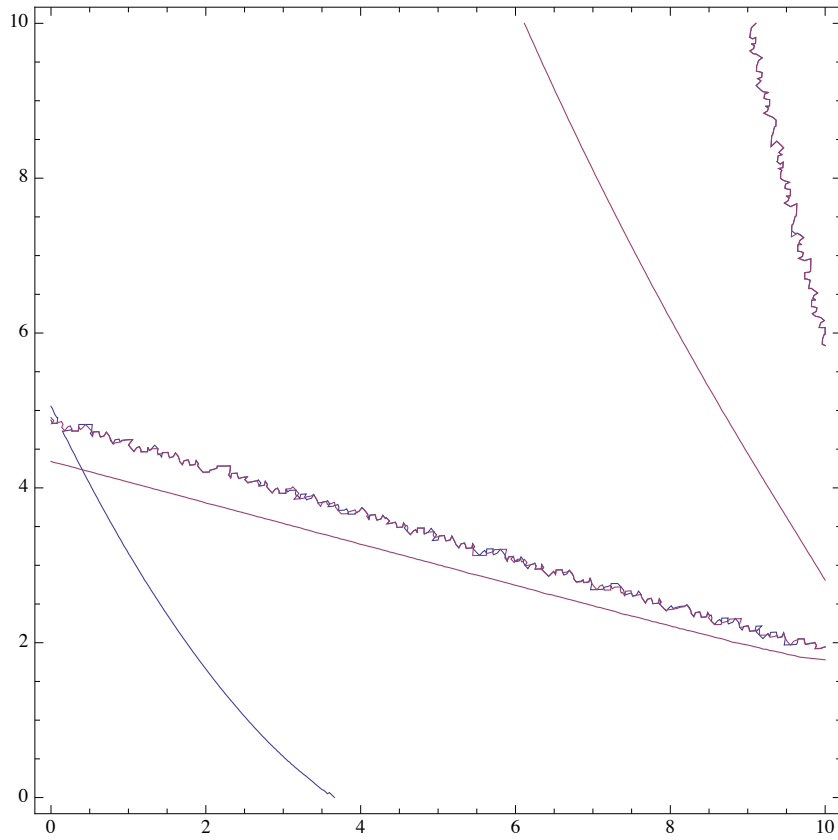
$(Rs (Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) +$

$nTc (Roc (Rmp - Rs) ((Voc - Vmp) - Rs Imp) - Rs (Voc - Rs Isc) (Rmp - Roc))$

$Rsh := \frac{(Roc - Rs) (Rmp - Rs) ((Voc - Vmp) - Rs Imp)}{(Roc - Rs) (Rmp - Rs) Imp - nTc (Rmp - Roc)}$

$ContourPlot \left[\left\{ \left(\frac{Rsh}{Rmp - Rs} - 1 \right) - \left(\frac{Rsh}{Roc - Rs} - 1 \right) e^{\frac{Vmp + Rs Imp - Voc}{nTc}} == 0, \right. \right.$

$$\left(\frac{R_{sh}}{R_{sc} - R_s} - 1 \right) - \left(\frac{R_{sh}}{R_{oc} - R_s} - 1 \right) e^{\frac{R_s I_{sc} - V_{oc}}{nTc}} = 0, \{R_s, 0, 10\}, \{nTc, 0, 10\}$$



Voc := 66.4
Isc := 3.65
Vmp := 54
Imp := 3.33
VM := 19
IM := 3.63

$$R_{mp} := \frac{V_{mp}}{I_{mp}}$$

$$R_{oc} := \left(R_s (R_{mp} - R_s) \left((V_{oc} - V_{mp}) I_M - (V_{oc} - V_M) I_{mp} \right) - \right.$$

$$\left. R_{mp} nTc \left((V_{oc} - V_M) - R_s I_M \right) + nTc \left(R_{mp} nTc + (V_{oc} - V_{mp}) (R_{mp} - R_s) \right) \left(1 - e^{-\frac{R_s I_M - (V_{oc} - V_M)}{nTc}} \right) \right) /$$

$$\left((R_{mp} - R_s) \left((V_{oc} - V_{mp}) I_M - (V_{oc} - V_M) I_{mp} \right) - nTc \left((V_{oc} - V_M) - R_s I_M \right) + \right.$$

$$\begin{aligned}
& nTc \left(nTc + (Rmp - Rs) Imp \right) \left(1 - e^{-\frac{Rs IM - (Voc - VM)}{nTc}} \right) \\
Rsc := & 1 / \left((Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) + \right. \\
& \left. nTc \left((Rmp - Rs) \left((Voc - Vmp) - Rs Imp \right) - (Voc - Rs Isc) (Rmp - Roc) \right) \right) \\
& (Rs (Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) + \\
& nTc (Roc (Rmp - Rs) \left((Voc - Vmp) - Rs Imp \right) - Rs (Voc - Rs Isc) (Rmp - Roc)))
\end{aligned}$$

$$Rsh := \frac{(Roc - Rs) (Rmp - Rs) \left((Voc - Vmp) - Rs Imp \right)}{(Roc - Rs) (Rmp - Rs) Imp - nTc (Rmp - Roc)}$$

$$ans = \{Rs, nTc\} /. \text{FindRoot} \left[\left\{ \left(\frac{Rsh}{Rmp - Rs} - 1 \right) - \left(\frac{Rsh}{Roc - Rs} - 1 \right) e^{\frac{Vmp + Rs Imp - Voc}{nTc}} == 0, \right. \right.$$

$$\left. \left(\frac{Rsh}{Rsc - Rs} - 1 \right) - \left(\frac{Rsh}{Roc - Rs} - 1 \right) e^{\frac{Rs Isc - Voc}{nTc}} == 0 \right\}, \{\{Rs, 0\}, \{nTc, 4\}\}]$$

$$Rs = \text{Extract}[ans, 1]$$

$$nTc = \text{Extract}[ans, 2]$$

$$\begin{aligned}
Roc = & \left(Rs (Rmp - Rs) \left((Voc - Vmp) IM - (Voc - VM) Imp \right) - \right. \\
& \left. Rmp nTc \left((Voc - VM) - Rs IM \right) + nTc \left(Rmp nTc + (Voc - Vmp) (Rmp - Rs) \right) \left(1 - e^{-\frac{Rs IM - (Voc - VM)}{nTc}} \right) \right) / \\
& \left((Rmp - Rs) \left((Voc - Vmp) IM - (Voc - VM) Imp \right) - nTc \left((Voc - VM) - Rs IM \right) + \right. \\
& \left. nTc \left(nTc + (Rmp - Rs) Imp \right) \left(1 - e^{-\frac{Rs IM - (Voc - VM)}{nTc}} \right) \right)
\end{aligned}$$

$$\begin{aligned}
Rsc = & 1 / \left((Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) + \right. \\
& \left. nTc \left((Rmp - Rs) \left((Voc - Vmp) - Rs Imp \right) - (Voc - Rs Isc) (Rmp - Roc) \right) \right) \\
& (Rs (Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) + \\
& nTc (Roc (Rmp - Rs) \left((Voc - Vmp) - Rs Imp \right) - Rs (Voc - Rs Isc) (Rmp - Roc)))
\end{aligned}$$

$$Rsh = \frac{(Roc - Rs) (Rmp - Rs) \left((Voc - Vmp) - Rs Imp \right)}{(Roc - Rs) (Rmp - Rs) Imp - nTc (Rmp - Roc)}$$

$$IO = \frac{nTc Rs + Rsh - Roc}{Rsh Roc - Rs} e^{-\frac{Voc}{nTc}}$$

$$Iph = \frac{nTc Rs + Rsh - Roc}{Rsh Roc - Rs} + \frac{Voc}{Rsh} - IO$$

$$Rs + Rsh$$

$$\text{FindRoot} \left[Iph - IO \left(e^{\frac{0 + Rs y}{nTc}} - 1 \right) - \frac{0 + Rs y}{Rsh} - y == 0, \{y, 1\} \right]$$

```
FindRoot[Iph - I0 (e $\frac{Voc + Rs y}{nTc}$  - 1) -  $\frac{Voc + Rs y}{Rsh}$  - y == 0, {y, 0}]
```

```
FindRoot[Iph - I0 (e $\frac{Vmp + Rs y}{nTc}$  - 1) -  $\frac{Vmp + Rs y}{Rsh}$  - y, {y, 7}]
```

```
FindRoot[Iph - I0 (e $\frac{VM + Rs y}{nTc}$  - 1) -  $\frac{VM + Rs y}{Rsh}$  - y, {y, 7}]
```

```
Show[ListPlot[{{0, Isc}, {39.91, 3.59}, {VM, IM}, {Vmp, Imp}, {60.008, 1.996}, {Voc, 0}],
```

```
ContourPlot[Iph - I0 (e $\frac{x + Rs y}{nTc}$  - 1) -  $\frac{x + Rs y}{Rsh}$  - y == 0, {x, 0, 68}, {y, 0, 4}]]
```

```
{0.40368779983804354`, 4.236376736050907`}
```

```
0.40368779983804354`
```

```
4.236376736050907`
```

```
1.584951061474911`
```

```
953.1279472505902`
```

```
952.8937504059426`
```

```
5.585689501999227`*^-7
```

```
3.651546533251121`
```

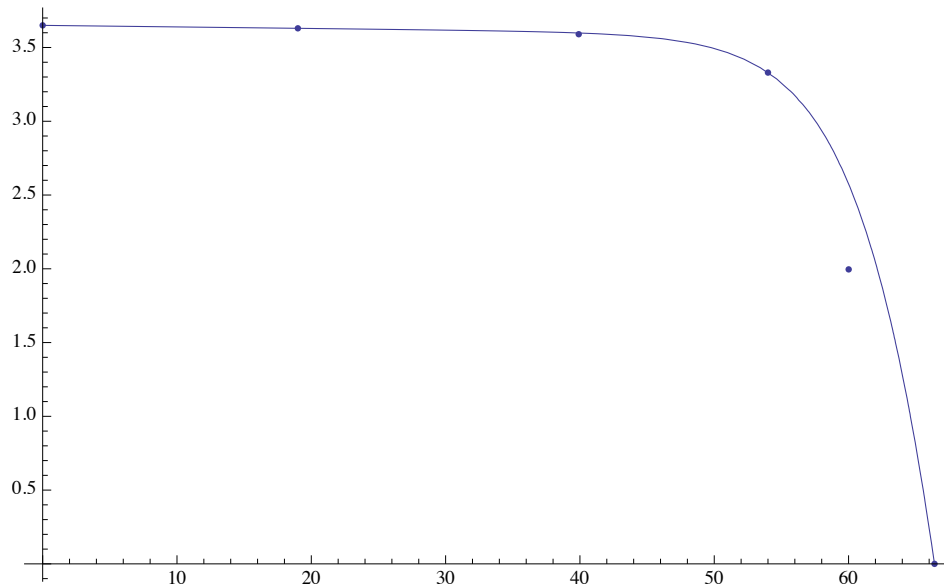
```
953.2974382057806`
```

```
{y → 3.6500000000000004`}
```

```
{y → 0.}`
```

```
{y → 3.33`}
```

```
{y → 3.629999999999999`}
```



Applicazione della soluzione analitica del modello equivalente a cinque parametri della cella fotovoltaica al pannello Sharp NT - 175 (E1) STC

Voc := 44.4
 Isc := 5.4
 Vmp := 35.4
 Imp := 4.95
 VM := 0.8
 IM := 5.398

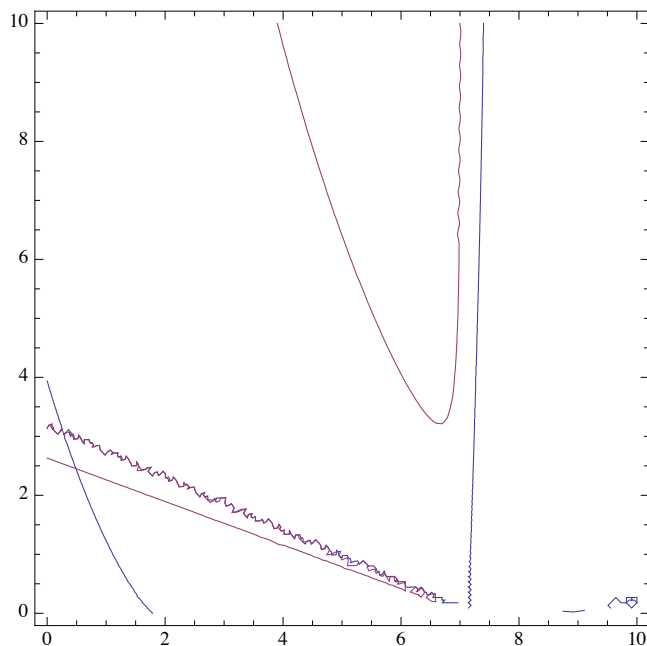
$$Rmp := \frac{Vmp}{Imp}$$

$$Roc := \left(Rs (Rmp - Rs) ((Voc - Vmp) IM - (Voc - VM) Imp) - \frac{Rmp nTc ((Voc - VM) - Rs IM) + nTc (Rmp nTc + (Voc - Vmp) (Rmp - Rs)) \left(1 - e^{-\frac{Rs IM - (Voc - VM)}{nTc}} \right)}{\left((Rmp - Rs) ((Voc - Vmp) IM - (Voc - VM) Imp) - nTc ((Voc - VM) - Rs IM) + nTc (nTc + (Rmp - Rs) Imp) \left(1 - e^{-\frac{Rs IM - (Voc - VM)}{nTc}} \right) \right)} \right)$$

$$Rsc := 1 / \left((Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) + nTc ((Rmp - Rs) ((Voc - Vmp) - Rs Imp) - (Voc - Rs Isc) (Rmp - Roc)) \right) + \left(Rs (Roc - Rs) (Rmp - Rs) (Voc Imp - (Voc - Vmp) Isc) + nTc (Roc (Rmp - Rs) ((Voc - Vmp) - Rs Imp) - Rs (Voc - Rs Isc) (Rmp - Roc)) \right)$$

$$Rsh := \frac{(Roc - Rs) (Rmp - Rs) ((Voc - Vmp) - Rs Imp)}{(Roc - Rs) (Rmp - Rs) Imp - nTc (Rmp - Roc)}$$

$$\text{ContourPlot} \left[\left\{ \left(\frac{Rsh}{Rmp - Rs} - 1 \right) - \left(\frac{Rsh}{Roc - Rs} - 1 \right) e^{\frac{Vmp + Rs Imp - Voc}{nTc}} = 0, \left(\frac{Rsh}{Rsc - Rs} - 1 \right) - \left(\frac{Rsh}{Roc - Rs} - 1 \right) e^{\frac{Rs Isc - Voc}{nTc}} = 0 \right\}, \{Rs, 0, 10\}, \{nTc, 0, 10\} \right]$$



Voc := 44.4
Isc := 5.4
Vmp := 35.4
Imp := 4.95
VM := 0.8
IM := 5.398

$$\mathbf{Rmp} := \frac{\mathbf{Vmp}}{\mathbf{Imp}}$$

$$\mathbf{Roc} := \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} := 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) + \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$\mathbf{Rsh} := \frac{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp})}{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp} - \mathbf{nTc} (\mathbf{Rmp} - \mathbf{Roc})}$$

$$\mathbf{ans} = \{\mathbf{Rs}, \mathbf{nTc}\} /. \mathbf{FindRoot} \left[\left\{ \left(\frac{\mathbf{Rsh}}{\mathbf{Rmp} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Vmp} + \mathbf{Rs} \mathbf{Imp} - \mathbf{Voc}}{\mathbf{nTc}}} = 0, \right. \right. \\ \left. \left. \left(\frac{\mathbf{Rsh}}{\mathbf{Rsc} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Rs} \mathbf{Isc} - \mathbf{Voc}}{\mathbf{nTc}}} = 0 \right\}, \{\{\mathbf{Rs}, 0.5\}, \{\mathbf{nTc}, 2.5\}\} \right]$$

Rs = Extract[ans, 1]

nTc = Extract[ans, 2]

$$\mathbf{Roc} = \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} = 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) + \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$R_{sh} = \frac{(R_{oc} - R_s) (R_{mp} - R_s) ((V_{oc} - V_{mp}) - R_s I_{mp})}{(R_{oc} - R_s) (R_{mp} - R_s) I_{mp} - nT_c (R_{mp} - R_{oc})}$$

$$I_0 = \frac{nT_c R_s + R_{sh} - R_{oc}}{R_{sh} R_{oc} - R_s} e^{-\frac{V_{oc}}{nT_c}}$$

$$I_{ph} = \frac{nT_c R_s + R_{sh} - R_{oc}}{R_{sh} R_{oc} - R_s} + \frac{V_{oc}}{R_{sh}} - I_0$$

Rs + Rsh

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{0+R_s y}{nT_c}} - 1\right) - \frac{0 + R_s y}{R_{sh}} - y == 0, \{y, 1\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_{oc}+R_s y}{nT_c}} - 1\right) - \frac{V_{oc} + R_s y}{R_{sh}} - y == 0, \{y, 0\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_{mp}+R_s y}{nT_c}} - 1\right) - \frac{V_{mp} + R_s y}{R_{sh}} - y, \{y, 7\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I_0 \left(e^{\frac{V_M+R_s y}{nT_c}} - 1\right) - \frac{V_M + R_s y}{R_{sh}} - y, \{y, 7\}\right]$$

Show

ListPlot[{{0, Iscr}, {20.431, 5.357}, {VM, IM}, {Vmp, Imp}, {41.158, 2.974}, {Voc, 0}},

ContourPlot[Iph - I0 (e^{x+Rs y/nTc} - 1) - x + Rs y/Rsh - y == 0, {x, 0, 45}, {y, 0, 6}]]

{0.488866, 2.45242}

0.488866

2.45242

0.951445

400.003

399.528

7.26415 × 10⁻⁸

5.40661

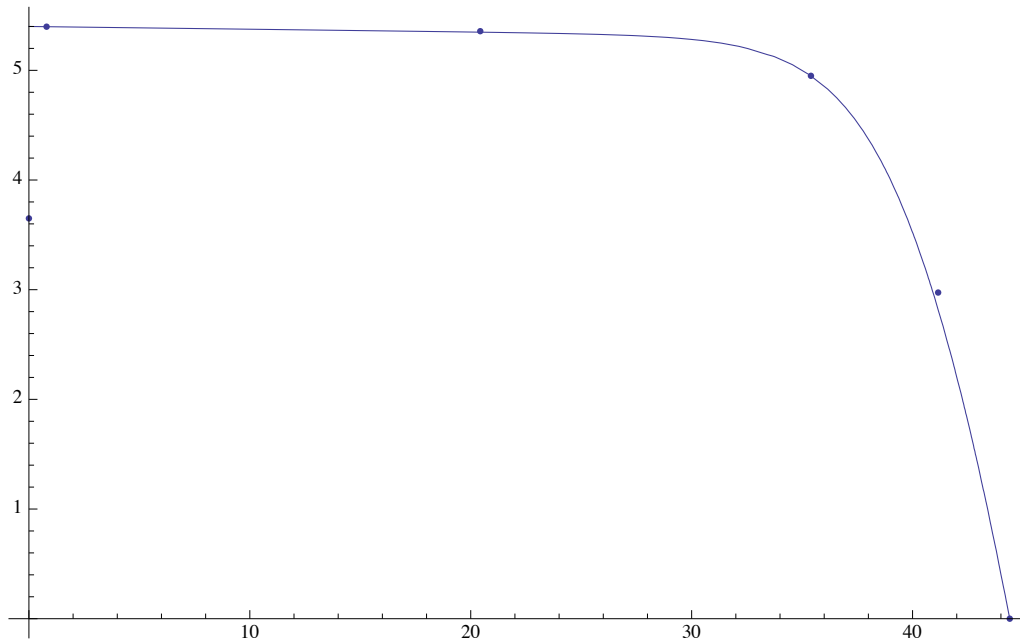
400.016

{y → 5.4}

{y → 0.}

{y → 4.95}

{y → 5.398}



Applicazione della soluzione analitica del modello equivalente a cinque parametri della cella fotovoltaica alla cella QCells Q6LMX3 STC

$V_{oc} := 0.608$

$I_{sc} := 8.6$

$V_{mp} := 0.5$

$I_{mp} := 8.29$

$V_M := 0.4$

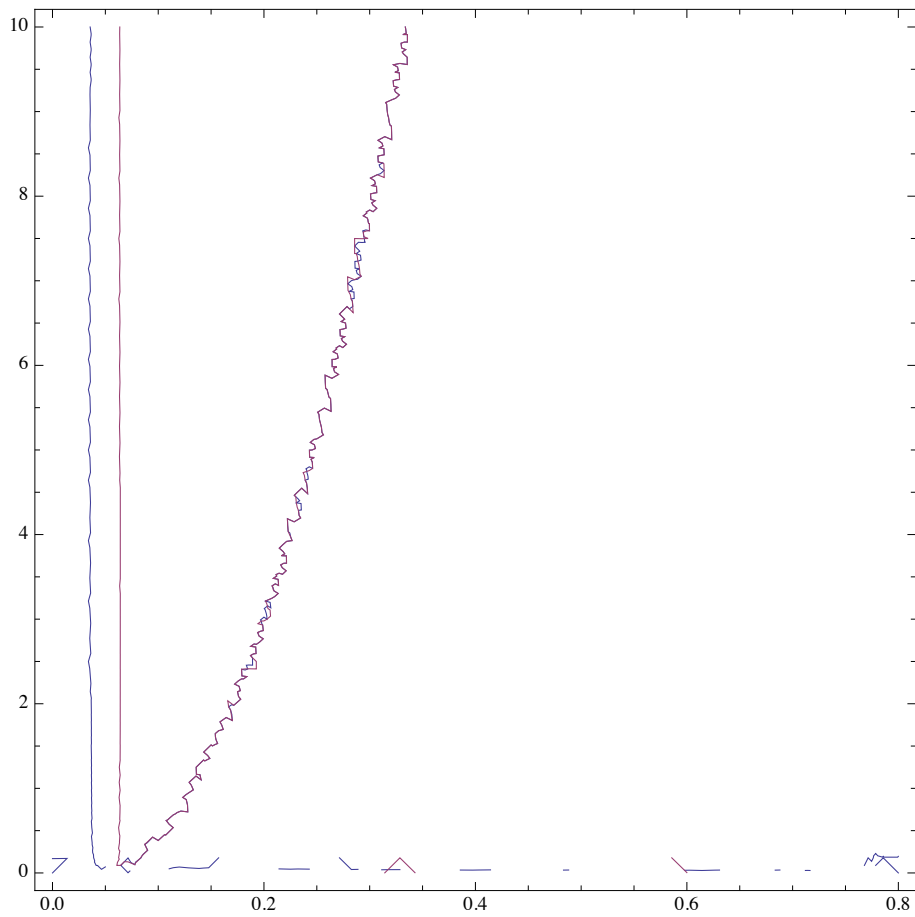
$I_M := 8.5$

$$R_{mp} := \frac{V_{mp}}{I_{mp}}$$

$$R_{oc} := \left(R_s (R_{mp} - R_s) \left((V_{oc} - V_{mp}) I_M - (V_{oc} - V_M) I_{mp} \right) - \right. \\ \left. R_{mp} nT_c \left((V_{oc} - V_M) - R_s I_M \right) + nT_c \left(R_{mp} nT_c + (V_{oc} - V_{mp}) (R_{mp} - R_s) \right) \left(1 - e^{-\frac{R_s I_M - (V_{oc} - V_M)}{nT_c}} \right) \right) / \\ \left((R_{mp} - R_s) \left((V_{oc} - V_{mp}) I_M - (V_{oc} - V_M) I_{mp} \right) - nT_c \left((V_{oc} - V_M) - R_s I_M \right) + \right. \\ \left. nT_c \left(nT_c + (R_{mp} - R_s) I_{mp} \right) \left(1 - e^{-\frac{R_s I_M - (V_{oc} - V_M)}{nT_c}} \right) \right) \\ R_{sc} := 1 / \left((R_{oc} - R_s) (R_{mp} - R_s) (V_{oc} I_{mp} - (V_{oc} - V_{mp}) I_{sc}) + \right. \\ \left. nT_c \left((R_{mp} - R_s) \left((V_{oc} - V_{mp}) - R_s I_{mp} \right) - (V_{oc} - R_s I_{sc}) (R_{mp} - R_{oc}) \right) \right) \\ \left(R_s (R_{oc} - R_s) (R_{mp} - R_s) (V_{oc} I_{mp} - (V_{oc} - V_{mp}) I_{sc}) + \right. \\ \left. nT_c (R_{oc} (R_{mp} - R_s) \left((V_{oc} - V_{mp}) - R_s I_{mp} \right) - R_s (V_{oc} - R_s I_{sc}) (R_{mp} - R_{oc})) \right)$$

$$\mathbf{Rsh} := \frac{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp})}{(\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp} - \mathbf{nTc} (\mathbf{Rmp} - \mathbf{Roc})}$$

$$\mathbf{ContourPlot} \left[\left\{ \left(\frac{\mathbf{Rsh}}{\mathbf{Rmp} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Vmp} + \mathbf{Rs} \mathbf{Imp} - \mathbf{Voc}}{\mathbf{nTc}}} == 0, \right. \right. \\ \left. \left. \left(\frac{\mathbf{Rsh}}{\mathbf{Rsc} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Rs} \mathbf{Isc} - \mathbf{Voc}}{\mathbf{nTc}}} == 0 \right\}, \{\mathbf{Rs}, 0, 0.8\}, \{\mathbf{nTc}, 0, 10\} \right]$$



Voc := 0.608
Isc := 8.6
Vmp := 0.5
Imp := 8.29
VM := 0.4
IM := 8.55

$$R_{mp} := \frac{V_{mp}}{I_{mp}}$$

$$R_{oc} := \left(R_s (R_{mp} - R_s) ((V_{oc} - V_{mp}) I_{M} - (V_{oc} - V_M) I_{mp}) - \right. \\ \left. R_{mp} n_{Tc} ((V_{oc} - V_M) - R_s I_M) + n_{Tc} (R_{mp} n_{Tc} + (V_{oc} - V_{mp}) (R_{mp} - R_s)) \left(1 - e^{-\frac{R_s I_M - (V_{oc} - V_M)}{n_{Tc}}} \right) \right) / \\ \left((R_{mp} - R_s) ((V_{oc} - V_{mp}) I_{M} - (V_{oc} - V_M) I_{mp}) - n_{Tc} ((V_{oc} - V_M) - R_s I_M) + \right. \\ \left. n_{Tc} (n_{Tc} + (R_{mp} - R_s) I_{mp}) \left(1 - e^{-\frac{R_s I_M - (V_{oc} - V_M)}{n_{Tc}}} \right) \right) \\ R_{sc} := 1 / ((R_{oc} - R_s) (R_{mp} - R_s) (V_{oc} I_{mp} - (V_{oc} - V_{mp}) I_{sc}) + \\ n_{Tc} ((R_{mp} - R_s) ((V_{oc} - V_{mp}) - R_s I_{mp}) - (V_{oc} - R_s I_{sc}) (R_{mp} - R_{oc})) \\ (R_s (R_{oc} - R_s) (R_{mp} - R_s) (V_{oc} I_{mp} - (V_{oc} - V_{mp}) I_{sc}) + \\ n_{Tc} (R_{oc} (R_{mp} - R_s) ((V_{oc} - V_{mp}) - R_s I_{mp}) - R_s (V_{oc} - R_s I_{sc}) (R_{mp} - R_{oc})))$$

$$R_{sh} := \frac{(R_{oc} - R_s) (R_{mp} - R_s) ((V_{oc} - V_{mp}) - R_s I_{mp})}{(R_{oc} - R_s) (R_{mp} - R_s) I_{mp} - n_{Tc} (R_{mp} - R_{oc})}$$

$$ans = \{R_s, n_{Tc}\} /. \text{FindRoot} \left[\left\{ \left(\frac{R_{sh}}{R_{mp} - R_s} - 1 \right) - \left(\frac{R_{sh}}{R_{oc} - R_s} - 1 \right) e^{-\frac{V_{mp} + R_s I_{mp} - V_{oc}}{n_{Tc}}} = 0, \right. \right. \\ \left. \left. \left(\frac{R_{sh}}{R_{sc} - R_s} - 1 \right) - \left(\frac{R_{sh}}{R_{oc} - R_s} - 1 \right) e^{-\frac{R_s I_{sc} - V_{oc}}{n_{Tc}}} = 0 \right\}, \{\{R_s, 0.7\}, \{n_{Tc}, 1\}\} \right]$$

$$R_s = \text{Extract}[ans, 1]$$

$$n_{Tc} = \text{Extract}[ans, 2]$$

$$R_{oc} = \left(R_s (R_{mp} - R_s) ((V_{oc} - V_{mp}) I_{M} - (V_{oc} - V_M) I_{mp}) - \right. \\ \left. R_{mp} n_{Tc} ((V_{oc} - V_M) - R_s I_M) + n_{Tc} (R_{mp} n_{Tc} + (V_{oc} - V_{mp}) (R_{mp} - R_s)) \left(1 - e^{-\frac{R_s I_M - (V_{oc} - V_M)}{n_{Tc}}} \right) \right) / \\ \left((R_{mp} - R_s) ((V_{oc} - V_{mp}) I_{M} - (V_{oc} - V_M) I_{mp}) - n_{Tc} ((V_{oc} - V_M) - R_s I_M) + \right. \\ \left. n_{Tc} (n_{Tc} + (R_{mp} - R_s) I_{mp}) \left(1 - e^{-\frac{R_s I_M - (V_{oc} - V_M)}{n_{Tc}}} \right) \right) \\ R_{sc} = 1 / ((R_{oc} - R_s) (R_{mp} - R_s) (V_{oc} I_{mp} - (V_{oc} - V_{mp}) I_{sc}) + \\ n_{Tc} ((R_{mp} - R_s) ((V_{oc} - V_{mp}) - R_s I_{mp}) - (V_{oc} - R_s I_{sc}) (R_{mp} - R_{oc})) \\ (R_s (R_{oc} - R_s) (R_{mp} - R_s) (V_{oc} I_{mp} - (V_{oc} - V_{mp}) I_{sc}) + \\ n_{Tc} (R_{oc} (R_{mp} - R_s) ((V_{oc} - V_{mp}) - R_s I_{mp}) - R_s (V_{oc} - R_s I_{sc}) (R_{mp} - R_{oc})))$$

$$R_{sh} = \frac{(R_{oc} - R_s) (R_{mp} - R_s) ((V_{oc} - V_{mp}) - R_s I_{mp})}{(R_{oc} - R_s) (R_{mp} - R_s) I_{mp} - n_{Tc} (R_{mp} - R_{oc})}$$

$$I_0 = \frac{n_{Tc} R_s + R_{sh} - R_{oc}}{R_{sh} - R_{oc} - R_s} e^{-\frac{V_{oc}}{n_{Tc}}}$$

$$I_{ph} = \frac{nTc}{Rsh} \frac{Rs + Rsh - Roc}{Roc - Rs} + \frac{Voc}{Rsh} - I0$$

Rs + Rsh

$$\text{FindRoot}\left[I_{ph} - I0 \left(e^{\frac{0+Rs y}{nTc}} - 1\right) - \frac{0 + Rs y}{Rsh} - y == 0, \{y, 1\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I0 \left(e^{\frac{Voc+Rs y}{nTc}} - 1\right) - \frac{Voc + Rs y}{Rsh} - y == 0, \{y, 0\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I0 \left(e^{\frac{Vmp+Rs y}{nTc}} - 1\right) - \frac{Vmp + Rs y}{Rsh} - y, \{y, 7\}\right]$$

$$\text{FindRoot}\left[I_{ph} - I0 \left(e^{\frac{VM+Rs y}{nTc}} - 1\right) - \frac{VM + Rs y}{Rsh} - y, \{y, 7\}\right]$$

Show[ListPlot[{{0, Isc}, {Vmp, Imp}, {VM, IM}, {Voc, 0}}],

ContourPlot[I_{ph} - I₀ (e ^{$\frac{x+Rs y}{nTc}$} - 1) - $\frac{x + Rs y}{Rsh}$ - y == 0, {x, 0, Voc}, {y, 0, Isc}]]

{4.911187954182572`*^13, 9.817893798897095`*^14}

4.911187954182572`*^13

9.817893798897095`*^14

-0.013070899215530821`

0.08786719599746676`

-4.911187954182588`*^13

-6.146077172187013`*^-14

-1.2379896792225226`*^-14

-0.1640625`

{y → 12.189552263597173`}

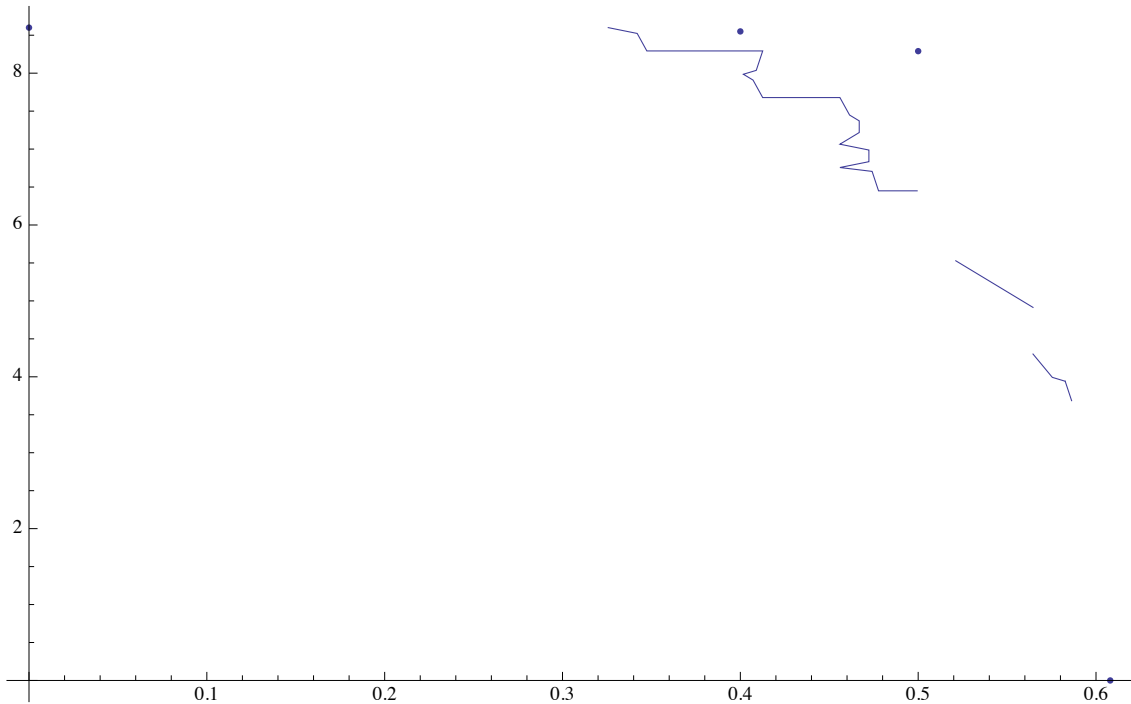
FindRoot::"lstol" :

"!\(\(*StyleBox[\"\\\"The line search decreased the step size to within tolerance specified by AccuracyGoal and PrecisionGoal but was unable to find a sufficient decrease in the merit function. You may need more than \\\"\", \"MT\\\")\)\)\!\(\(*StyleBox[\"\\\"(MachinePrecision)\", \"MT\\\"]\)\)\!\(\(*StyleBox[\"\\\" digits of working precision to meet these tolerances.\\\"\", \"MT\\\"]\)\)\)\!\(\(*ButtonBox[\">>\", ButtonStyle->\"Link\", ButtonFrame->None, ButtonData:>\"paclet:ref/message/FindRoot/lstol\", ButtonNote -> \"FindRoot::lstol\"]\)\)"

{y → 1.086545849532569`*^-15}

{y → 6.999409219629452`}

{y → 9.270284007451105`}



Applicazione della soluzione analitica del modello equivalente a cinque parametri della cella fotovoltaica al pannello SEM160 STC

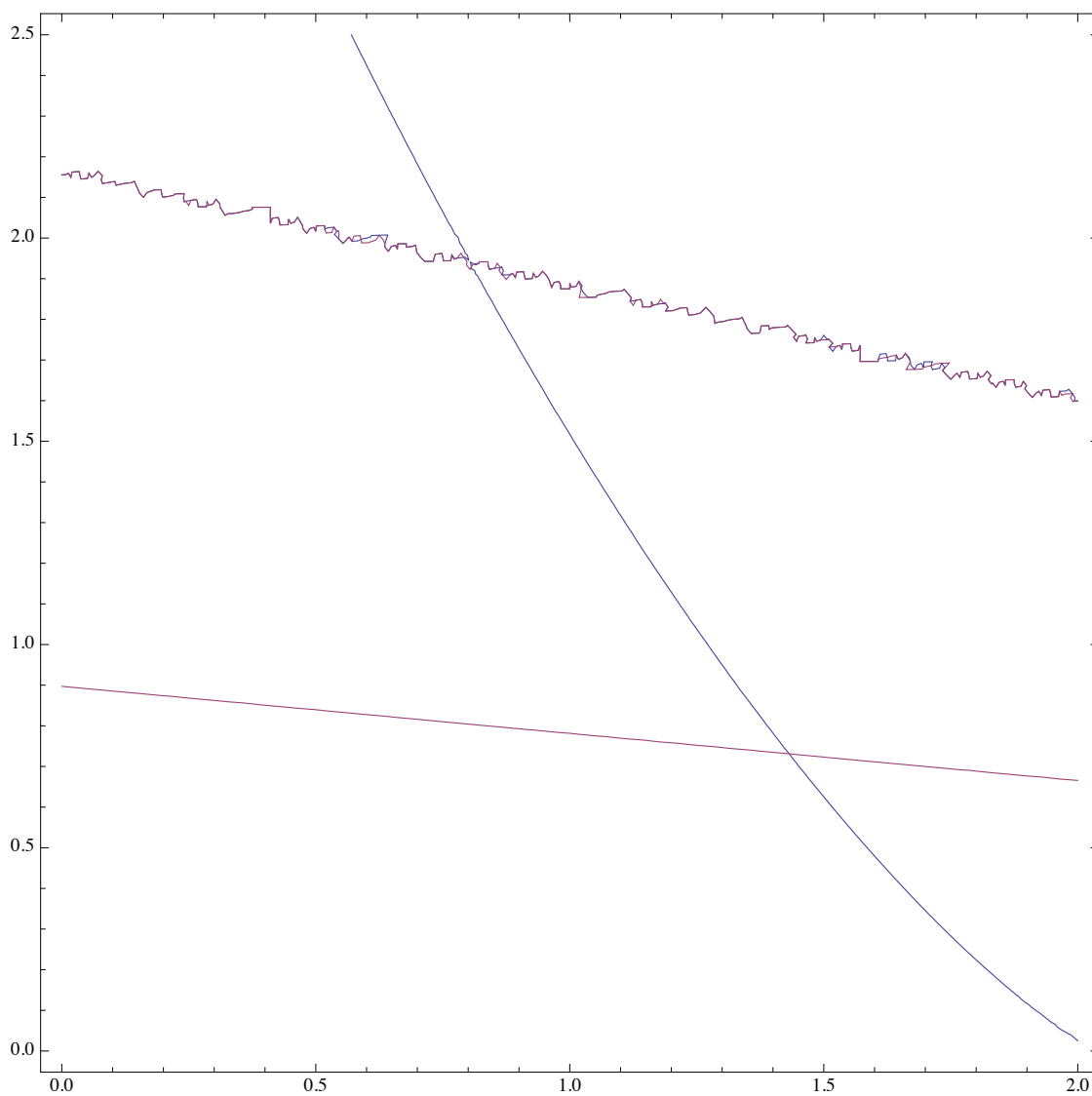
Voc := 43
Isc := 4.7
Vmp := 34
Imp := 4.4
VM := 3.6
IM := 4.68

Rmp := $\frac{Vmp}{Imp}$

Roc := $\left(R_s (Rmp - R_s) \left((Voc - Vmp) IM - (Voc - VM) Imp \right) - \right.$
 $Rmp nTc \left((Voc - VM) - R_s IM \right) + nTc \left(Rmp nTc + (Voc - Vmp) (Rmp - R_s) \right) \left(1 - e^{\frac{R_s IM - (Voc - VM)}{nTc}} \right) \right) /$
 $\left((Rmp - R_s) \left((Voc - Vmp) IM - (Voc - VM) Imp \right) - nTc \left((Voc - VM) - R_s IM \right) + \right.$
 $nTc \left(nTc + (Rmp - R_s) Imp \right) \left(1 - e^{\frac{R_s IM - (Voc - VM)}{nTc}} \right) \left. \right)$
Rsc := $1 / \left((Roc - R_s) (Rmp - R_s) (Voc Imp - (Voc - Vmp) Isc) + \right.$
 $nTc \left((Rmp - R_s) \left((Voc - Vmp) - R_s Imp \right) - (Voc - R_s Isc) (Rmp - Roc) \right) +$
 $(R_s (Roc - R_s) (Rmp - R_s) (Voc Imp - (Voc - Vmp) Isc) +$
 $nTc (Roc (Rmp - R_s) \left((Voc - Vmp) - R_s Imp \right) - R_s (Voc - R_s Isc) (Rmp - Roc) \right)$

$$\mathbf{Rsh} := \frac{((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Vmp} - \mathbf{Rs Imp}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs Imp}))}{((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Vmp} - \mathbf{Rs Imp}) \mathbf{Imp} - \mathbf{nTc} (\mathbf{Vmp} - \mathbf{Roc Imp}))}$$

$$\mathbf{ContourPlot} \left[\left\{ \left(\frac{\mathbf{Rsh}}{\mathbf{Rmp} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Vmp} + \mathbf{Rs Imp} - \mathbf{Voc}}{\mathbf{nTc}}} = 0, \right. \right. \\ \left. \left. \left(\frac{\mathbf{Rsh}}{\mathbf{Rsc} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Rs Isc} - \mathbf{Voc}}{\mathbf{nTc}}} = 0 \right\}, \{\mathbf{Rs}, 0, 2\}, \{\mathbf{nTc}, 0, 2.5\} \right]$$



Voc := 43
Isc := 4.7
Vmp := 34
Imp := 4.4
VM := 3.6
IM := 4.68

$$\mathbf{Rmp} := \frac{\mathbf{Vmp}}{\mathbf{Imp}}$$

$$\mathbf{Roc} := \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{-\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{-\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} := 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) + \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$\mathbf{Rsh} := ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Vmp} - \mathbf{Rs} \mathbf{Imp}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp})) / \\ ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Vmp} - \mathbf{Rs} \mathbf{Imp}) \mathbf{Imp} - \mathbf{nTc} (\mathbf{Vmp} - \mathbf{Roc} \mathbf{Imp})) \\ \mathbf{ans} = \{\mathbf{Rs}, \mathbf{nTc}\} /. \mathbf{FindRoot} \left[\left[\left(\frac{\mathbf{Rsh}}{\mathbf{Rmp} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Vmp} + \mathbf{Rs} \mathbf{Imp} - \mathbf{Voc}}{\mathbf{nTc}}} = 0, \right. \right. \\ \left. \left. \left(\frac{\mathbf{Rsh}}{\mathbf{Rsc} - \mathbf{Rs}} - 1 \right) - \left(\frac{\mathbf{Rsh}}{\mathbf{Roc} - \mathbf{Rs}} - 1 \right) e^{\frac{\mathbf{Rs} \mathbf{Isc} - \mathbf{Voc}}{\mathbf{nTc}}} = 0 \right], \{\{\mathbf{Rs}, 0.75\}, \{\mathbf{nTc}, 1.5\}\} \right] \\ \mathbf{Rs} = \mathbf{Extract}[\mathbf{ans}, 1] \\ \mathbf{nTc} = \mathbf{Extract}[\mathbf{ans}, 2]$$

$$\mathbf{Roc} = \left(\mathbf{Rs} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \right. \\ \left. \mathbf{Rmp} \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \mathbf{nTc} (\mathbf{Rmp} \mathbf{nTc} + (\mathbf{Voc} - \mathbf{Vmp}) (\mathbf{Rmp} - \mathbf{Rs})) \left(1 - e^{-\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) / \\ \left((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM}) \mathbf{Imp}) - \mathbf{nTc} ((\mathbf{Voc} - \mathbf{VM}) - \mathbf{Rs} \mathbf{IM}) + \right. \\ \left. \mathbf{nTc} (\mathbf{nTc} + (\mathbf{Rmp} - \mathbf{Rs}) \mathbf{Imp}) \left(1 - e^{-\frac{\mathbf{Rs} \mathbf{IM} - (\mathbf{Voc} - \mathbf{VM})}{\mathbf{nTc}}} \right) \right) \\ \mathbf{Rsc} = 1 / ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} ((\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})) + \\ (\mathbf{Rs} (\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Rmp} - \mathbf{Rs}) (\mathbf{Voc} \mathbf{Imp} - (\mathbf{Voc} - \mathbf{Vmp}) \mathbf{Isc}) + \\ \mathbf{nTc} (\mathbf{Roc} (\mathbf{Rmp} - \mathbf{Rs}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp}) - \mathbf{Rs} (\mathbf{Voc} - \mathbf{Rs} \mathbf{Isc}) (\mathbf{Rmp} - \mathbf{Roc})))$$

$$\mathbf{Rsh} = ((\mathbf{Roc} - \mathbf{Rs}) (\mathbf{Vmp} - \mathbf{Rs} \mathbf{Imp}) ((\mathbf{Voc} - \mathbf{Vmp}) - \mathbf{Rs} \mathbf{Imp})) /$$

$$((Roc - Rs) (Vmp - Rs Imp) Imp - nTc (Vmp - Roc Imp))$$

$$I0 = \frac{nTc}{Rsh} \frac{Rs + Rsh - Roc}{Roc - Rs} e^{-\frac{Voc}{nTc}}$$

$$Iph = \frac{nTc}{Rsh} \frac{Rs + Rsh - Roc}{Roc - Rs} + \frac{Voc}{Rsh} - I0$$

Rs + Rsh

$$\text{FindRoot}\left[Iph - I0 \left(e^{\frac{0+Rs y}{nTc}} - 1\right) - \frac{0 + Rs y}{Rsh} - y == 0, \{y, 1\}\right]$$

$$\text{FindRoot}\left[Iph - I0 \left(e^{\frac{Voc+Rs y}{nTc}} - 1\right) - \frac{Voc + Rs y}{Rsh} - y == 0, \{y, 0\}\right]$$

$$\text{FindRoot}\left[Iph - I0 \left(e^{\frac{Vmp+Rs y}{nTc}} - 1\right) - \frac{Vmp + Rs y}{Rsh} - y, \{y, 7\}\right]$$

$$\text{FindRoot}\left[Iph - I0 \left(e^{\frac{VM+Rs y}{nTc}} - 1\right) - \frac{VM + Rs y}{Rsh} - y, \{y, 7\}\right]$$

Show[ListPlot[{{0, 4.7}, {3.6, 4.68}, {34, 4.4}, {43, 0}}],

ContourPlot[Iph - I0 (e ^{$\frac{x+Rs y}{nTc}$} - 1) - $\frac{x + Rs y}{Rsh}$ - y == 0, {x, 0, 43}, {y, 0, 4.7}]]

{1.4321128976218838[^], 0.7308364973750057[^]}

1.4321128976218838[^]

0.7308364973750057[^]

1.5944855766673736[^]

179.99999999875388[^]

178.56788710254344[^]

1.2602672322564827[^] * 10⁻²⁵

4.7376939590205405[^]

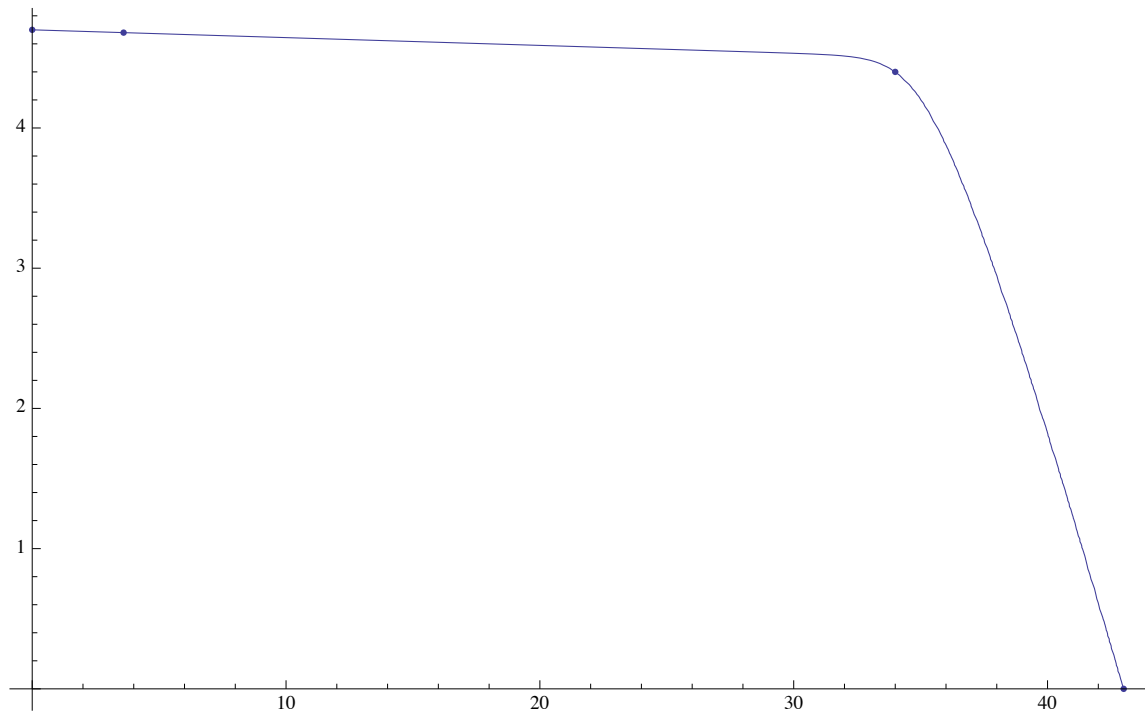
180.0000000016533[^]

{y → 4.700000000000028[^]}

{y → 0.[^]}

{y → 4.4[^]}

{y → 4.680000000000046[^]}



A4

Applicazione della soluzione analitica approssimata del modello equivalente a cinque parametri della cella fotovoltaica al pannello Kyocera KC175 - GHT2 STC

Vocr := 29.2

Iscr := 8.09

Vmpr := 23.6

Impr := 7.42

Xscale := 205.7

Yscale := 184.8

$$Vsr = \frac{Vocr \cdot 35.75}{Xscale}$$

$$Isr = \frac{Iscr \cdot 183}{Yscale}$$

Rocr :=

$$1 / \left(\left((Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr \right) \right. \\ \left. + (Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) \right)$$

Plot [Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)

$$e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr (Iscr - Impr) - Vmpr)}} - Vsr == 0, \{Rscr, 0, 100\}$$

ans = Rscr / . FindRoot [Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)

$$e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr (Iscr - Impr) - Vmpr)}} - Vsr == 0, \{Rscr, 65\}$$

Rscr := ans

Rocr :=

$$1 / \left(\left((Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr \right) \right. \\ \left. + (Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] - (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) \right)$$

Rsr := (Rocr (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) -

Vmpr (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)) /

((Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - (Rscr - Rocr) Impr (Rscr (Iscr - Impr) - Vmpr))

Rshr := Rscr - Rsr

nTr := ((Rocr - Rsr) (Rscr Iscr - Vocr)) / (Rscr - Rocr)

$$I0r := \frac{(Rscr Iscr - Vocr)}{Rscr - Rsr} * e^{\frac{-Vocr (Rscr - Rocr)}{(Rocr - Rsr) (Rscr Iscr - Vocr)}}$$

Rscr - Rsr

Rscr Iscr

Iphr := $\frac{Rscr Iscr}{Rscr - Rsr} - I0r$

FindRoot [Iphr - I0r $\left(e^{\frac{0 + Rsr y}{nTr}} - 1 \right) - \frac{0 + Rsr y}{Rshr} - y == 0, \{y, 9\}$]

```
FindRoot[Iphr - IOr (e $\frac{29.2 + Rsr y}{nTr}$  - 1) -  $\frac{29.2 + Rsr y}{Rshr}$  - y == 0, {y, 0}]
```

```
FindRoot[Iphr - IOr (e $\frac{23.6 + Rsr y}{nTr}$  - 1) -  $\frac{23.6 + Rsr y}{Rshr}$  - y == 0, {y, 7.5}]
```

```
FindRoot[Iphr - IOr (e $\frac{Vsr + Rsr y}{nTr}$  - 1) -  $\frac{Vsr + Rsr y}{Rshr}$  - y == 0, {y, 7.5}]
```

```
Show[ListPlot[{{0, 8.09}, {5.102, 8.011}, {10.135, 7.924}, {20.412, 7.727},
{23.6, 7.42}, {25.656, 5.975}, {27.145, 3.969}, {28.279, 1.992}, {29.2, 0}}],
```

```
ContourPlot[Iphr - IOr * (e $\frac{x + Rsr * y}{nTr}$  - 1) -  $\frac{x + Rsr * y}{Rshr}$  - y == 0, {x, 0, 30}, {y, 0, 9}],
```

```
Frame -> True, AspectRatio -> 1 / 1]
```

```
Rscr
```

```
Rocr
```

```
Rsr
```

```
Rshr
```

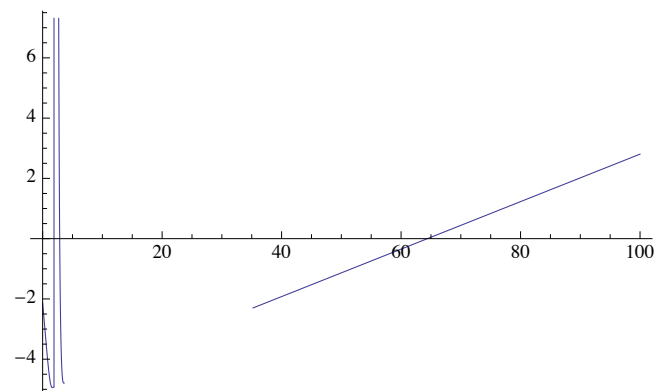
```
nTr
```

```
IOr
```

```
Iphr
```

```
5.07487
```

```
8.0112
```



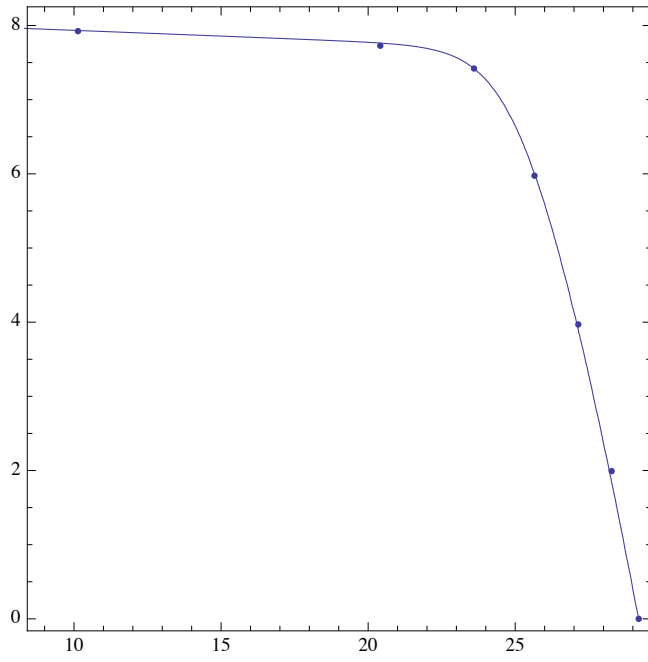
```
64.4029
```

```
{y -> 8.09}
```

```
{y -> 0.}
```

```
{y -> 7.42}
```

```
{y -> 8.0112}
```



64.4029

0.480655

0.363747

64.0392

0.899496

6.12374×10^{-14}

8.13595

```

Voc := 29.2
Isc := 8.09
Vmp := 23.6
Imp := 7.42
Rso = 0.42
Rsho = 99.44
T = 298

```

```
Rsh := Rsho
```

$$Vt = \frac{1.380658 \cdot 10^{-23} \cdot T}{1.6021773 \cdot 10^{-19}}$$

$$m = (Vmp + Imp \cdot Rso - Voc) / \left(Vt \left(\log \left[Isc - \frac{Vmp}{Rsho} - Imp \right] - \log \left[Isc - \frac{Voc}{Rsho} \right] + \frac{Imp}{Isc - \frac{Voc}{Rsho}} \right) \right)$$

$$Rs = Rso - \frac{m \cdot Vt}{\left(Isc - \frac{Voc}{Rsho} \right)}$$

$$I0 := \left(Isc - \frac{Voc}{Rsho} \right) e^{\left(\frac{-Voc}{m \cdot Vt} \right)}$$

$$IL := Isc \left(1 + \frac{Rs}{Rsho} \right) + I0 \left(e^{\frac{Isc \cdot Rs}{m \cdot Vt}} - 1 \right)$$

$$\text{FindRoot} \left[IL - I0 \left(e^{\frac{0+Rs \cdot y}{m \cdot Vt}} - 1 \right) - \frac{0 + Rs \cdot y}{Rsh} - y == 0, \{y, 9\} \right]$$

$$\text{FindRoot} \left[IL - I0 \left(e^{\frac{29.2+Rs \cdot y}{m \cdot Vt}} - 1 \right) - \frac{29.2 + Rs \cdot y}{Rsh} - y == 0, \{y, 0\} \right]$$

$$\text{FindRoot} \left[IL - I0 \left(e^{\frac{23.6+Rs \cdot y}{m \cdot Vt}} - 1 \right) - \frac{23.6 + Rs \cdot y}{Rsh} - y == 0, \{y, 7.5\} \right]$$

$$\text{FindRoot} \left[IL - I0 \left(e^{\frac{5.102+Rs \cdot y}{m \cdot Vt}} - 1 \right) - \frac{5.102 + Rs \cdot y}{Rsh} - y == 0, \{y, 7.5\} \right]$$

```
Show[ListPlot[{{0, 8.09}, {5.102, 8.011}, {10.135, 7.924}, {20.412, 7.727}, {23.6, 7.42},
{25.656, 5.975}, {27.145, 3.969}, {28.279, 1.992}, {29.2, 0}}, PlotStyle -> Black],
```

```
ContourPlot[IL - I0 (e^(x+Rs y / (m Vt)) - 1) - (x + Rs y) / Rsho - y == 0, {x, 0, Voc},
{y, 0, Isc}, ContourStyle -> {Dashed, Thick, Red}],
```

```
ContourPlot[Iphr - I0r * (e^(x+Rsr*y / (n*Vt)) - 1) - (x + Rsr * y) / Rshr - y == 0, {x, 0, 30},
{y, 0, 9}, ContourStyle -> {Dashed, Thick, Orange}]]
```

```
Rs
```

```
Rsh
```

```
m Vt
```

```
I0
```

```
IL
```

```
0.42
```

```
99.44
```

```
298
```

```
0.0256798
```

```
49.8602
```

```
0.25577
```

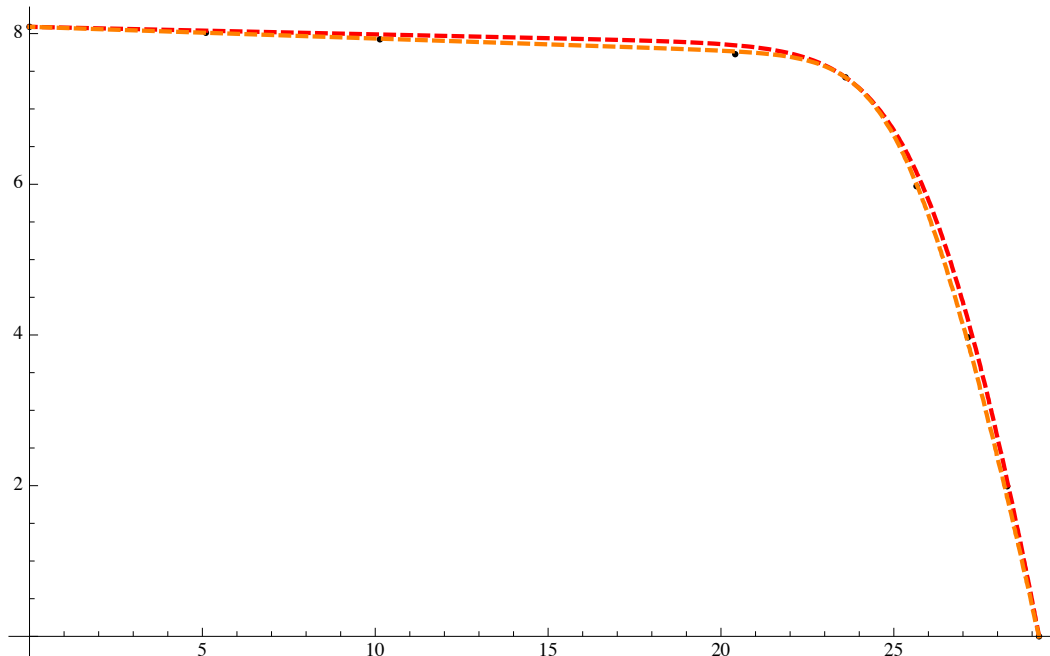

{y → 8.09}

{y → 0.00812437}

{y → 7.42158}

{y → 8.038824053133904}

Confronto con il metodo proposto da Celik et al



0.25577

99.44

1.2804

9.71938×10^{-10}

8.11081

Applicazione della soluzione analitica approssimata del modello equivalente a cinque parametri della cella fotovoltaica al pannello Kyocera KC175 - GHT2 NOCT

Vocr := 26.5

Iscr := 6.53

Vmpr := 20.9

Impr := 5.99

Xscale := 205.7

Yscale := 184.8

$$Vsr = \frac{Vocr \ 35.75}{Xscale}$$

$$Isr = \frac{Iscr \ 183}{Yscale}$$

$$Rocr := 1 / \left(\left((Rscr \ (Isr - Impr) - Vmpr) \ ((2 \ Vmpr - Vocr) + (Rscr \ Iscr - Vocr) \ Log[(Rscr \ (Isr - Impr) - Vmpr) / (Rscr \ Iscr - Vocr)]) + (Rscr \ Iscr - Vocr) \ (Rscr \ Impr - Vmpr) \right) \ Impr \right) \left((Rscr \ (Isr - Impr) - Vmpr) \left((2 \ Vmpr - Vocr) \ Rscr \ Impr + Vmpr \ (Rscr \ Iscr - Vocr) \ Log \left[\frac{Rscr \ (Isr - Impr) - Vmpr}{Rscr \ Iscr - Vocr} \right] \right) - (Vmpr - Vocr) \ (Rscr \ Iscr - Vocr) \ (Rscr \ Impr - Vmpr) \right)$$

$$Plot \left[Rscr \ (Isr - Isr) - (Rscr \ Iscr - Vocr) \frac{(Vsr - Vocr + Rocr \ Isr) \ (Rscr \ Iscr - Vocr) \ (Rscr \ Impr - Vmpr) - ((Vsr - Vocr) \ Impr - Vmpr \ Isr) \ (Rscr - Rocr) \ (Rscr \ (Isr - Impr) - Vmpr)}{(Vmpr - Rocr \ Impr) \ (Rscr \ Iscr - Vocr) \ (Rscr \ (Isr - Impr) - Vmpr)} - Vsr == 0, \{Rscr, 0, 100\} \right]$$

$$FindRoot \left[Rscr \ (Isr - Isr) - (Rscr \ Iscr - Vocr) \frac{(Vsr - Vocr + Rocr \ Isr) \ (Rscr \ Iscr - Vocr) \ (Rscr \ Impr - Vmpr) - ((Vsr - Vocr) \ Impr - Vmpr \ Isr) \ (Rscr - Rocr) \ (Rscr \ (Isr - Impr) - Vmpr)}{(Vmpr - Rocr \ Impr) \ (Rscr \ Iscr - Vocr) \ (Rscr \ (Isr - Impr) - Vmpr)} - Vsr == 0, \{Rscr, 65\} \right]$$

$$Rscr := 72.41089879297891$$

$$Rocr =$$

$$1 / \left(\left((Rscr \ (Isr - Impr) - Vmpr) \ ((2 \ Vmpr - Vocr) + (Rscr \ Iscr - Vocr) \ Log[(Rscr \ (Isr - Impr) - Vmpr) / (Rscr \ Iscr - Vocr)]) + (Rscr \ Iscr - Vocr) \ (Rscr \ Impr - Vmpr) \right) \ Impr \right) \left((Rscr \ (Isr - Impr) - Vmpr) \ ((2 \ Vmpr - Vocr) \ Rscr \ Impr + Vmpr \ (Rscr \ Iscr - Vocr) \ Log[(Rscr \ (Isr - Impr) - Vmpr) / (Rscr \ Iscr - Vocr)]) - (Vmpr - Vocr) \ (Rscr \ Iscr - Vocr) \ (Rscr \ Impr - Vmpr) \right)$$

$$Rsr = (Rocr \ (Rscr \ Iscr - Vocr) \ (Rscr \ Impr - Vmpr) - Vmpr \ (Rscr - Rocr) \ (Rscr \ (Isr - Impr) - Vmpr)) / ((Rscr \ Iscr - Vocr) \ (Rscr \ Impr - Vmpr) - (Rscr - Rocr) \ Impr \ (Rscr \ (Isr - Impr) - Vmpr))$$

$$Rshr = Rscr - Rsr$$

$$nTr = ((Rocr - Rsr) \ (Rscr \ Iscr - Vocr)) / (Rscr - Rocr) \frac{(Rscr \ Iscr - Vocr) \ (-Vocr \ (Rscr - Rocr))}{(Rocr - Rsr) \ (Rscr \ Iscr - Vocr)}$$

$$I0r = \frac{Rscr - Rsr}{Rscr \ Iscr} * e^{\frac{-Vocr \ (Rscr - Rocr)}{(Rocr - Rsr) \ (Rscr \ Iscr - Vocr)}}$$

$$Iphr = \frac{Rscr \ Iscr}{Rscr - Rsr} - I0r$$

$$FindRoot \left[Iphr - I0r \left(e^{\frac{0 + Rsr \ y}{nTr}} - 1 \right) - \frac{0 + Rsr \ y}{Rshr} - y == 0, \{y, Iscr\} \right]$$

$$FindRoot \left[Iphr - I0r \left(e^{\frac{Vocr + Rsr \ y}{nTr}} - 1 \right) - \frac{Vocr + Rsr \ y}{Rshr} - y == 0, \{y, 0\} \right]$$

$$FindRoot \left[Iphr - I0r \left(e^{\frac{Vmpr + Rsr \ y}{nTr}} - 1 \right) - \frac{Vmpr + Rsr \ y}{Rshr} - y == 0, \{y, Impr\} \right]$$

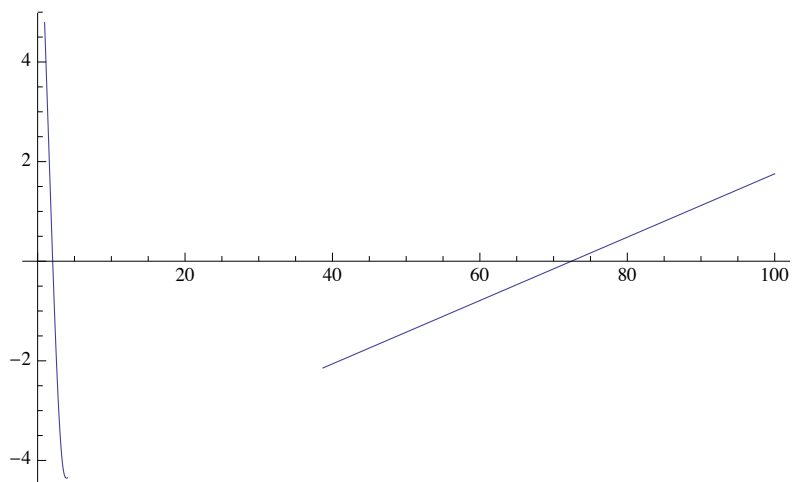
$$FindRoot \left[Iphr - I0r \left(e^{\frac{Vsr + Rsr \ y}{nTr}} - 1 \right) - \frac{Vsr + Rsr \ y}{Rshr} - y == 0, \{y, Isr\} \right]$$

$$Show \left[ListPlot[\{0, 8.09\}, \{5.102, 8.011\}, \{10.135, 7.924\}, \{20.412, 7.727\},$$

```
{23.6, 7.42}, {25.656, 5.975}, {27.145, 3.969}, {28.279, 1.992}, {29.2, 0}],
ContourPlot[6.56966390306543 - 4.306753865896087 × 10-13 * (e $\frac{x+0.48171881159084334*y}{0.87448111470857412}$  - 1) -
(x + 0.48171881159084334 * y) / 79.30696670130983 - y == 0, {x, 0, 30}, {y, 0, 10}],
AspectRatio -> 3 / 2, PlotRange -> {{0, 30}, {0, 10}}, Frame -> True, GridLines -> Automatic]
```

4.60561

6.4664



{72.4109 → 72.4109}

0.641674

0.515394

71.8955

0.785353

 1.37616×10^{-14}

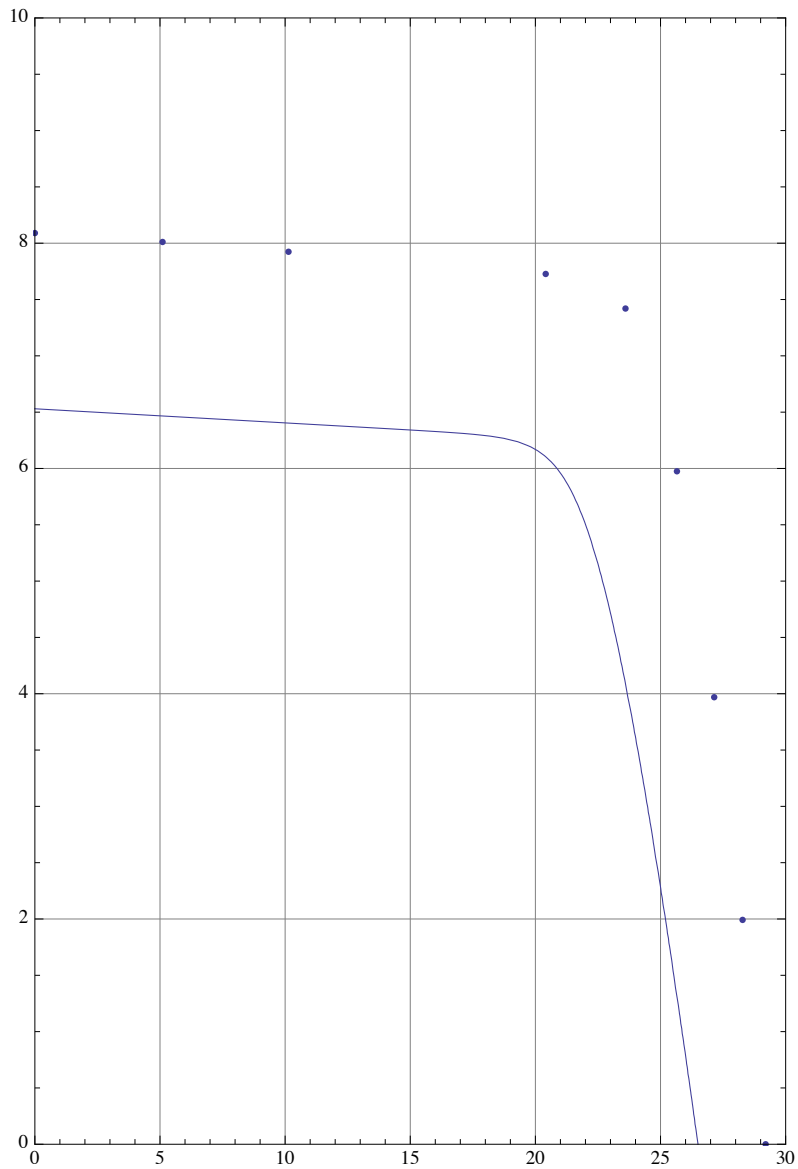
6.57681

{y → 6.53}

{y → 8.68495×10^{-15} }

{y → 5.99}

{y → 6.4664}



Applicazione della soluzione analitica approssimata del modello equivalente a cinque parametri della cella fotovoltaica al pannello Sanyo HIP180 - BA19 STC

Vocr := 66.4

Iscr := 3.65

Vmpr := 54

Impr := 3.33

Vsr = 19

Isr = 3.63

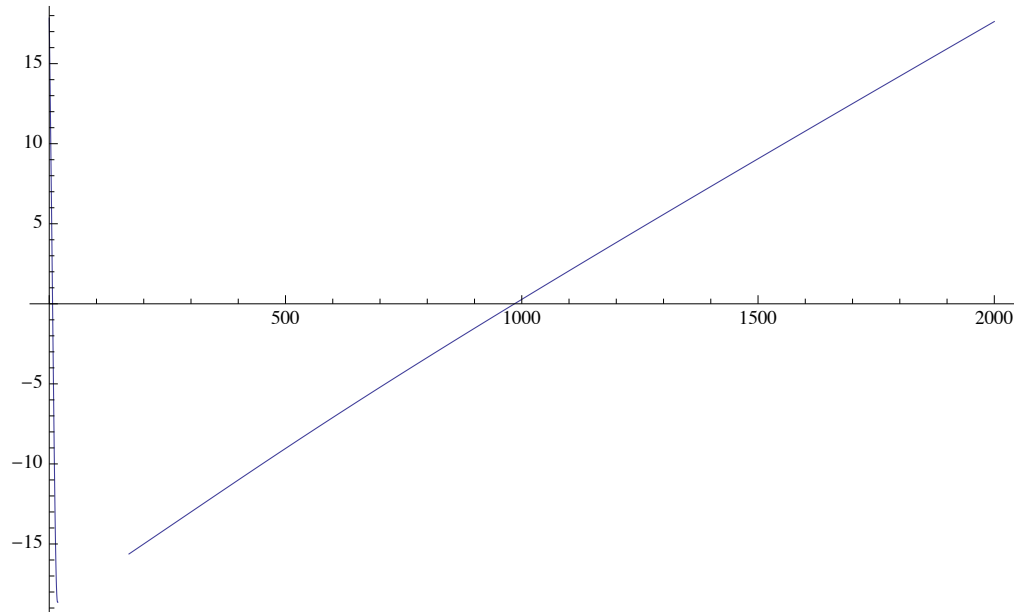
```

Rocr :=
1 / (((Rscr (Iscr - Impr) - Vmpr) ((2 Vmpr - Voccr) + (Rscr Iscr - Voccr) Log[(Rscr (Iscr - Impr) -
Vmpr) / (Rscr Iscr - Voccr)]) + (Rscr Iscr - Voccr) (Rscr Impr - Vmpr)) Impr)
((Rscr (Iscr - Impr) - Vmpr) ((2 Vmpr - Voccr) Rscr Impr + Vmpr (Rscr Iscr - Voccr)
Log[(Rscr (Iscr - Impr) - Vmpr) / (Rscr Iscr - Voccr)]) -
(Vmpr - Voccr) (Rscr Iscr - Voccr) (Rscr Impr - Vmpr))
Plot[Rscr (Iscr - Isr) - (Rscr Iscr - Voccr)
e(Vsr-Vocr+Rocr Isr) (Rscr Iscr-Vocr) (Rscr Impr-Vmpr) - ((Vsr-Vocr) Impr-Vmpr Isr) (Rscr-Rocr) (Rscr (Iscr-Impr)-Vmpr)
(Vmpr-Rocr Impr) (Rscr Iscr-Vocr) (Rscr (Iscr-Impr)-Vmpr) - Vsr == 0, {Rscr, 0, 2000}]

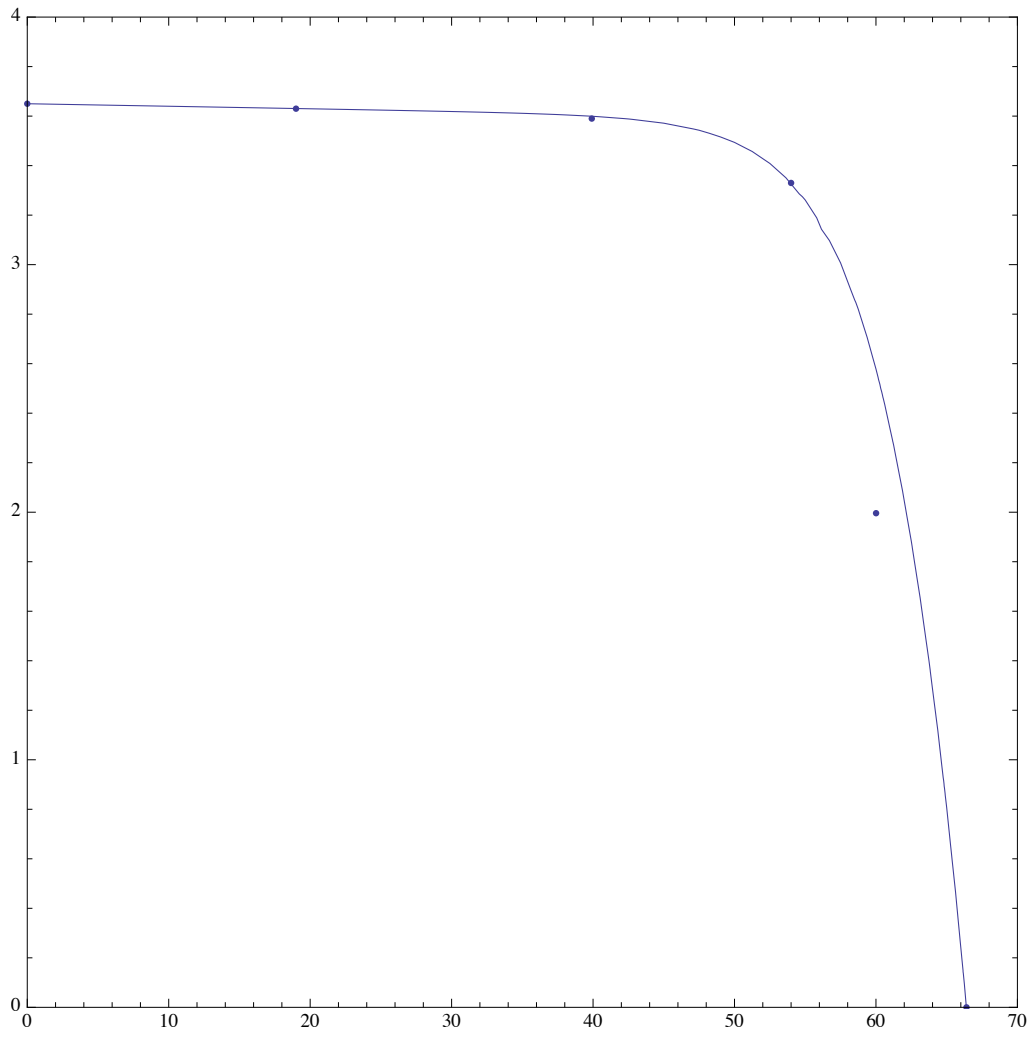
ans = Rscr /. FindRoot[Rscr (Iscr - Isr) - (Rscr Iscr - Voccr)
e(Vsr-Vocr+Rocr Isr) (Rscr Iscr-Vocr) (Rscr Impr-Vmpr) - ((Vsr-Vocr) Impr-Vmpr Isr) (Rscr-Rocr) (Rscr (Iscr-Impr)-Vmpr)
(Vmpr-Rocr Impr) (Rscr Iscr-Vocr) (Rscr (Iscr-Impr)-Vmpr) - Vsr == 0, {Rscr, 1000}]

Rscr := ans
Rocr =
1 / (((Rscr (Iscr - Impr) - Vmpr) ((2 Vmpr - Voccr) + (Rscr Iscr - Voccr) Log[(Rscr (Iscr - Impr) -
Vmpr) / (Rscr Iscr - Voccr)]) + (Rscr Iscr - Voccr) (Rscr Impr - Vmpr)) Impr)
((Rscr (Iscr - Impr) - Vmpr) ((2 Vmpr - Voccr) Rscr Impr + Vmpr (Rscr Iscr - Voccr)
Log[(Rscr (Iscr - Impr) - Vmpr) / (Rscr Iscr - Voccr)]) -
(Vmpr - Voccr) (Rscr Iscr - Voccr) (Rscr Impr - Vmpr))
Rsr = (Rocr (Rscr Iscr - Voccr) (Rscr Impr - Vmpr) - Vmpr (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)) /
((Rscr Iscr - Voccr) (Rscr Impr - Vmpr) - (Rscr - Rocr) Impr (Rscr (Iscr - Impr) - Vmpr))
Rshr = Rscr - Rsr
nTr = ((Rocr - Rsr) (Rscr Iscr - Voccr)) / (Rscr - Rocr)
IOr =  $\frac{(Rscr Iscr - Voccr) e^{-Vocr (Rscr - Rocr)}}{Rscr - Rsr} * e^{(Rocr - Rsr) (Rscr Iscr - Voccr)}$ 
Iphr =  $\frac{Rscr Iscr}{Rscr - Rsr} - IOr$ 
Iscc = h /. FindRoot[Iphr - IOr (e $\frac{0+Rsr h}{nTr} - 1$  - 1) -  $\frac{0 + Rsr h}{Rshr} - h == 0, \{h, Iscr\}]$ 
Ioc = x /. FindRoot[Iphr - IOr (e $\frac{Vocr+Rsr x}{nTr} - 1$  - 1) -  $\frac{Vocr + Rsr x}{Rshr} - x == 0, \{x, 0\}]$ 
Imprc = y /. FindRoot[Iphr - IOr (e $\frac{Vmpr+Rsr y}{nTr} - 1$  - 1) -  $\frac{Vmpr + Rsr y}{Rshr} - y == 0, \{y, Impr\}]$ 
Isrcc = z /. FindRoot[Iphr - IOr (e $\frac{Vsr+Rsr z}{nTr} - 1$  - 1) -  $\frac{Vsr + Rsr z}{Rshr} - z == 0, \{z, Isr\}]$ 

Show[
ListPlot[{{0, 3.65}, {39.91, 3.59}, {Vsr, Isr}, {54, 3.33}, {60.008, 1.996}, {66.4, 0}],
ContourPlot[Iphr - IOr * (e $\frac{x+Rsr y}{nTr} - 1$  - 1) -  $\frac{x + Rsr * y}{Rshr} - y == 0, \{x, 0, 70\}, \{y, 0, 4\}],
AspectRatio -> 1 / 1, PlotRange -> {{0, 70}, {0, 4}}, Frame -> True]
19
3.63`$ 
```



984.5848977807624`
1.576566233425867`
0.38731740985912655`
984.1975803709032`
4.267388910199686`
6.26325966355961`*^-7
3.6514357809302407`
3.649999128026291`
5.0562423671497145`*^-15
3.33`
3.630627817250983`



Applicazione della soluzione analitica approssimata del modello equivalente a cinque parametri della cella fotovoltaica al pannello Sharp NT - 175 (E1) STC

Vocr := 44.4
 Iscr := 5.4
 Vmpr := 35.4
 Impr := 4.95
 Vsr = 0.8
 Isr = 5.398

Rocr :=

$$\frac{1}{\left(\frac{(Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr}{(Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \right) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr)} \right)}$$

Plot [Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)

$$e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr (Iscr - Impr) - Vmpr)}} - Vsr == 0, \{Rscr, 0, 1000\}]$$

ans = Rscr /. FindRoot [Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)

$$e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr (Iscr - Impr) - Vmpr)}} - Vsr == 0, \{Rscr, 1000\}]$$

Rscr := ans

Rocr :=

$$\frac{1}{\left(\frac{(Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr}{(Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \right) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] - (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr)} \right)}$$

Rsr := (Rocr (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) -

$$Vmpr (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)) /$$

$$\left((Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - (Rscr - Rocr) Impr (Rscr (Iscr - Impr) - Vmpr) \right)$$

Rshr := Rscr - Rsr

nTr := ((Rocr - Rsr) (Rscr Iscr - Vocr)) / (Rscr - Rocr)

$$I0r := \frac{(Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - (Rscr - Rocr) Impr (Rscr (Iscr - Impr) - Vmpr)}{(Rscr - Rsr) * e^{\frac{-Vocr (Rscr - Rocr)}{(Rocr - Rsr) (Rscr Iscr - Vocr)}}}$$

$$Iphr := \frac{Rscr Iscr}{Rscr - Rsr} - I0r$$

$$\text{FindRoot} \left[Iphr - I0r \left(e^{\frac{0 + Rsr y}{nTr}} - 1 \right) - \frac{0 + Rsr y}{Rshr} - y == 0, \{y, Iscr\} \right]$$

$$\text{FindRoot} \left[Iphr - I0r \left(e^{\frac{Vocr + Rsr y}{nTr}} - 1 \right) - \frac{Vocr + Rsr y}{Rshr} - y == 0, \{y, 0\} \right]$$

$$\text{FindRoot} \left[Iphr - I0r \left(e^{\frac{Vmpr + Rsr y}{nTr}} - 1 \right) - \frac{Vmpr + Rsr y}{Rshr} - y == 0, \{y, Impr\} \right]$$

$$\text{FindRoot} \left[Iphr - I0r \left(e^{\frac{Vsr + Rsr y}{nTr}} - 1 \right) - \frac{Vsr + Rsr y}{Rshr} - y == 0, \{y, Isr\} \right]$$

Show [ListPlot [

$$\{\{0, Iscr\}, \{20.431, 5.357\}, \{Vsr, Isr\}, \{Vmpr, Impr\}, \{41.158, 2.974\}, \{Vocr, 0\}\},$$

$$\text{ContourPlot} \left[Iphr - I0r * \left(e^{\frac{x + Rsr y}{nTr}} - 1 \right) - \frac{x + Rsr * y}{Rshr} - y == 0, \{x, 0, 45\}, \{y, 0, 6\} \right],$$

Frame → True, AspectRatio → 1 / 1]

Rscr

Rocr

Rsr

Rshr

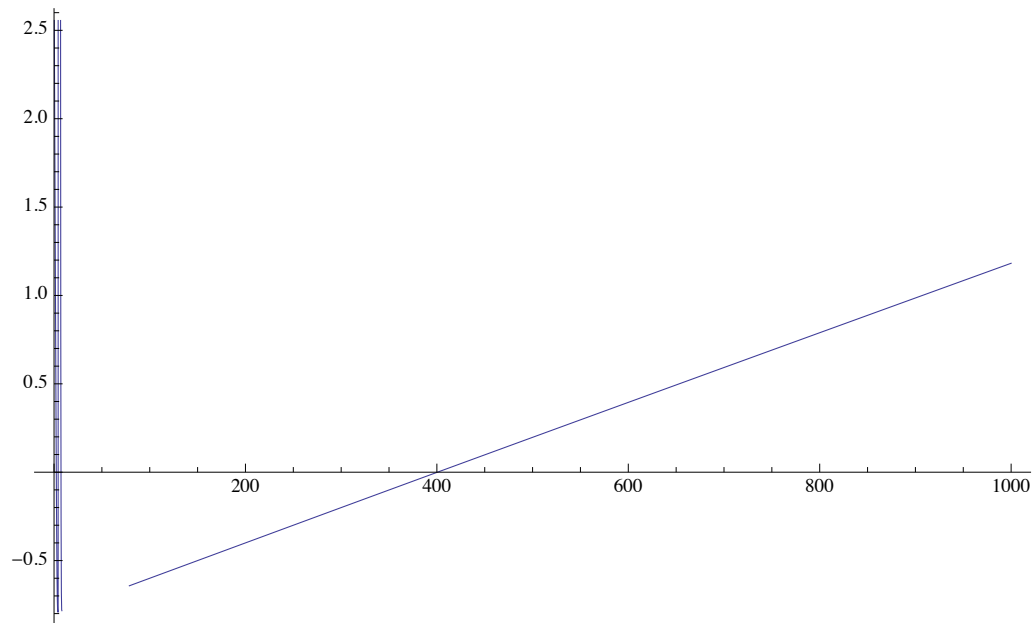
nTr

I0r

Iphr

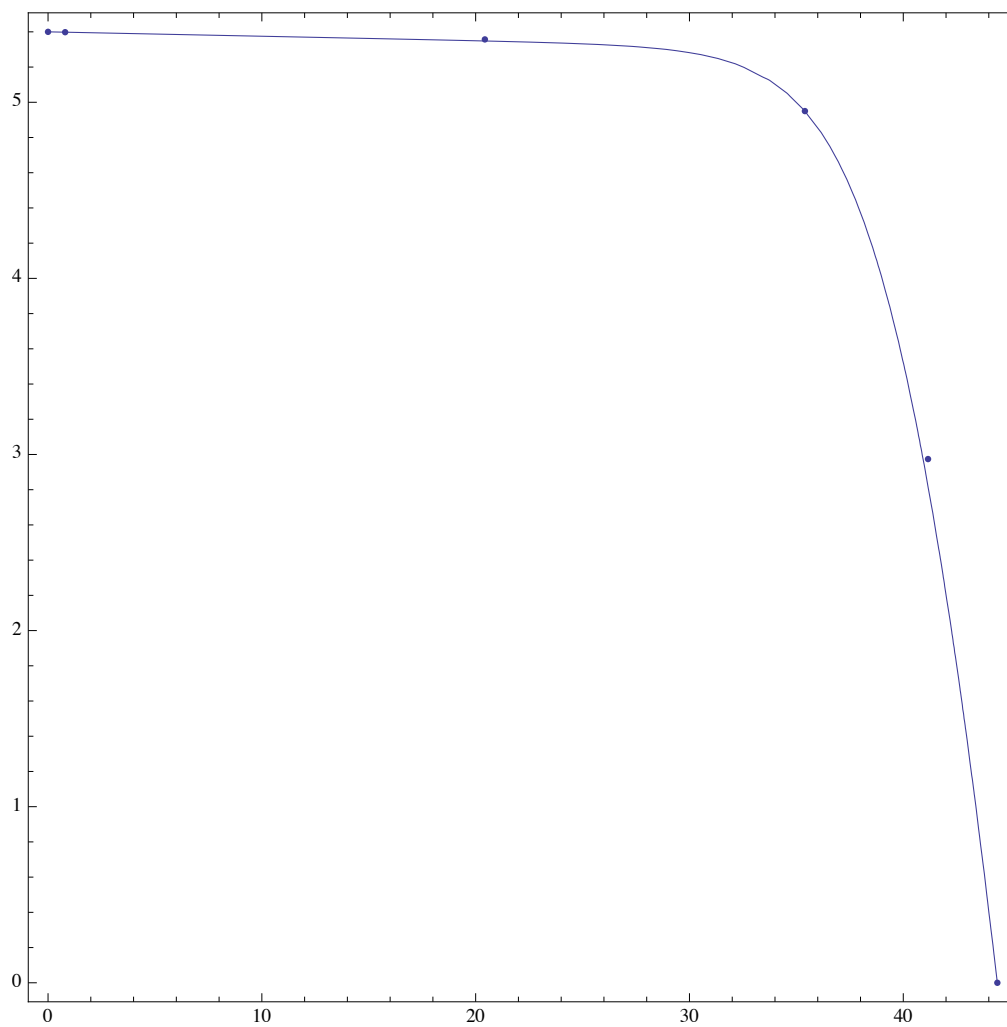
0.8

5.398



400.554

 $\{y \rightarrow 5.4\}$ $\{y \rightarrow 0.\}$ $\{y \rightarrow 4.95\}$ $\{y \rightarrow 5.398\}$



400.554

0.951278

0.488548

400.065

2.45328

7.31066×10^{-8}

5.40659

Applicazione della soluzione analitica approssimata del modello equivalente a cinque parametri della cella fotovoltaica al pannello Sharp NT - 175 (E1) NTC

Vocr := 44.4

Iscr := 5.4

Vmpr := 35.4

Impr := 4.95

Xscale := 108.09

Yscale := 132.39

$$Vsr := \frac{Vocr \cdot 32.24}{Xscale}$$

$$Isr = \frac{Iscr \cdot 130.2}{Yscale}$$

Rocr :=

$$\frac{1}{\left((Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr \right) + \left((Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] - (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) \right)}$$

Plot [Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)

$$e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr (Iscr - Impr) - Vmpr)}} - Vsr == 0, \{Rscr, 0, 2000\}]$$

FindRoot [Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)

$$e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr (Iscr - Impr) - Vmpr)}} - Vsr == 0, \{Rscr, 1000\}]$$

Rscr := 148.25572562924123

Rocr :=

$$\frac{1}{\left((Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr \right) + \left((Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] - (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) \right)}$$

Rsr := (Rocr (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) -

$$Vmpr (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)) /$$

$$(Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - (Rscr - Rocr) Impr (Rscr (Iscr - Impr) - Vmpr)$$

Rshr := Rscr - Rsr

nTr := ((Rocr - Rsr) (Rscr Iscr - Vocr)) / (Rscr - Rocr)

$$\frac{(Rscr Iscr - Vocr) \frac{-Vocr (Rscr - Rocr)}{(Rocr - Rsr) (Rscr Iscr - Vocr)}}{(Rscr - Rsr)}$$

I0r :=

$$Rscr - Rsr$$

Iphr := $\frac{Rscr Iscr}{Rscr - Rsr} - I0r$

$$\text{FindRoot} \left[Iphr - I0r \left(e^{\frac{0 + Rsr y}{nTr}} - 1 \right) - \frac{0 + Rsr y}{Rshr} - y == 0, \{y, Iscr\} \right]$$

$$\text{FindRoot} \left[Iphr - I0r \left(e^{\frac{Vocr + Rsr y}{nTr}} - 1 \right) - \frac{Vocr + Rsr y}{Rshr} - y == 0, \{y, 0\} \right]$$

$$\text{FindRoot} \left[Iphr - I0r \left(e^{\frac{Vmpr + Rsr y}{nTr}} - 1 \right) - \frac{Vmpr + Rsr y}{Rshr} - y == 0, \{y, Impr\} \right]$$

```
FindRoot[Iphr - IOr * (e^(Vsr + Rsr y / nTr) - 1) - (Vsr + Rsr y) / Rshr - y == 0, {y, Isr}]
```

```
Show[ListPlot[{{0, Iscr}, {Vsr, Isr}, {20.234, 5.286}, {30.397, 5.139}, {Vmpr, Impr},
{39.023, 3.956}, {40.736, 2.896}, {41.898, 2}, {43.131, 1}, {Vocr, 0}]]],
```

```
ContourPlot[Iphr - IOr * (e^(x + Rsr y / nTr) - 1) - (x + Rsr y) / Rshr - y == 0, {x, 0, 45}, {y, 0, 6}],
```

```
AspectRatio -> 3 / 2, PlotRange -> {{0, 45}, {0, 6}}, Frame -> True]
```

```
Rscr
```

```
Rocr
```

```
Rsr
```

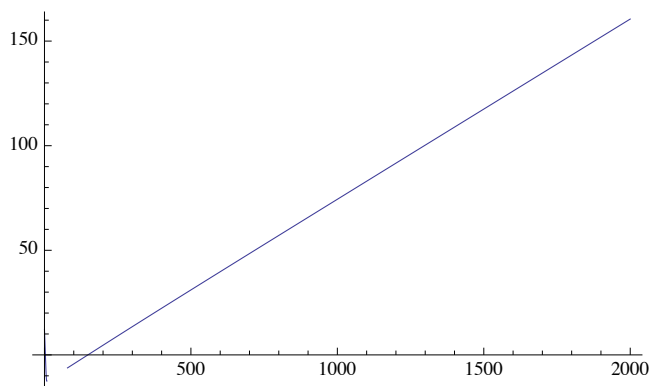
```
Rshr
```

```
nTr
```

```
IOr
```

```
Iphr
```

```
5.31067
```



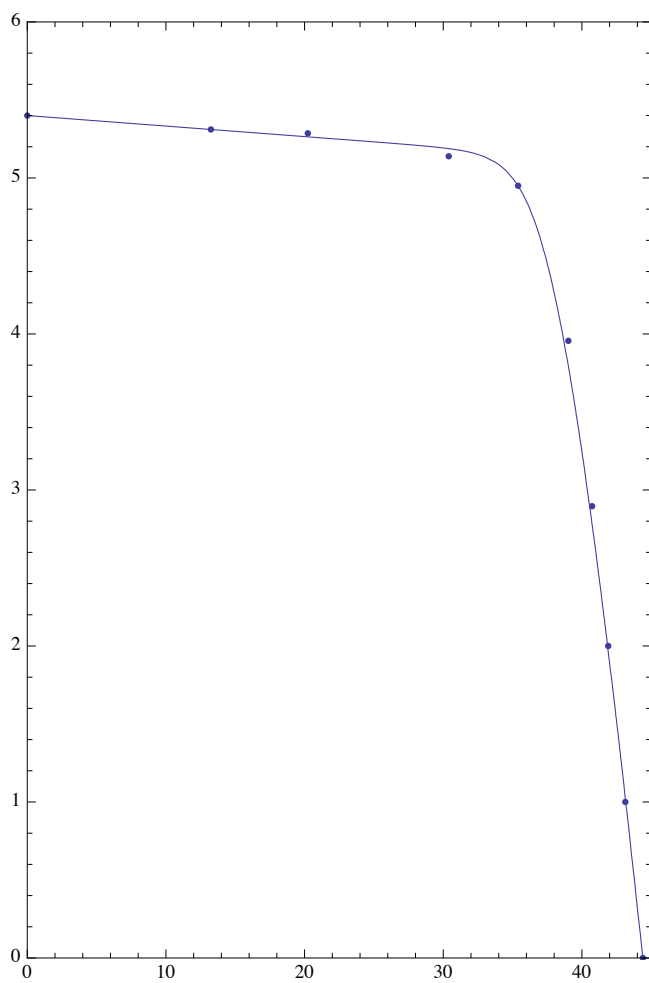
```
{63.2911 -> 148.256}
```

```
{y -> 5.4}
```

```
{y -> 0.}
```

```
{y -> 4.95}
```

```
{y -> 5.31067}
```



148.256

1.19852

0.929999

147.326

1.38073

 5.55665×10^{-14}

5.43409

Applicazione della soluzione analitica approssimata del modello equivalente a cinque parametri della cella fotovoltaica alla cella QCells Q6LMX3 NTC

Vocr := 0.608

Iscr := 8.6

Vmpr := 0.5

Impr := 8.29

Vsr := 0.4

Isr = 8.4

Rocr :=

$$\frac{1}{\left(\frac{(Rscr(Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr(Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr}{(Rscr(Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \right) \log \left[\frac{Rscr(Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr)} \right)}$$

Plot $\left[\frac{Rscr(Iscr - Isr) - (Rscr Iscr - Vocr)}{e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr(Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr(Iscr - Impr) - Vmpr)}}} - Vsr == 0, \{Rscr, 0, 10000\} \right]$

FindRoot $\left[\frac{Rscr(Iscr - Isr) - (Rscr Iscr - Vocr)}{e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr(Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr(Iscr - Impr) - Vmpr)}}} - Vsr == 0, \{Rscr, 100\} \right]$

Rscr := 2.0000000000000617

Rocr :=

$$\frac{1}{\left(\frac{(Rscr(Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr(Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr}{(Rscr(Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \right) \log \left[\frac{Rscr(Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] - (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr)} \right)}$$

Rsr := (Rocr (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) -

Vmpr (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)) /

((Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - (Rscr - Rocr) Impr (Rscr (Iscr - Impr) - Vmpr))

Rshr := Rscr - Rsr

nTr := ((Rocr - Rsr) (Rscr Iscr - Vocr)) / (Rscr - Rocr)

IOr := $\frac{(Rscr Iscr - Vocr) \frac{-Vocr (Rscr - Rocr)}{Rscr - Rsr}}{e^{\frac{-Vocr (Rscr - Rocr)}{Rscr - Rsr}}} * e^{\frac{-Vocr (Rscr - Rocr)}{(Rscr Iscr - Vocr)}}$

Iphr := $\frac{Rscr Iscr}{Rscr - Rsr} - IOr$

FindRoot $\left[Iphr - IOr \left(e^{\frac{0 + Rsr y}{nTr}} - 1 \right) - \frac{0 + Rsr y}{Rshr} - y == 0, \{y, Iscr\} \right]$

FindRoot $\left[Iphr - IOr \left(e^{\frac{Vocr + Rsr y}{nTr}} - 1 \right) - \frac{Vocr + Rsr y}{Rshr} - y == 0, \{y, 0\} \right]$

FindRoot $\left[Iphr - IOr \left(e^{\frac{Vmpr + Rsr y}{nTr}} - 1 \right) - \frac{Vmpr + Rsr y}{Rshr} - y == 0, \{y, Impr\} \right]$

FindRoot $\left[Iphr - IOr \left(e^{\frac{Vsr + Rsr y}{nTr}} - 1 \right) - \frac{Vsr + Rsr y}{Rshr} - y == 0, \{y, Isr\} \right]$

Show $\left[\text{ListPlot}[\{\{0, Iscr\}, \{Vmpr, Impr\}, \{Vsr, Isr\}, \{Vocr, 0\}\}], \right]$

ContourPlot $\left[Iphr - IOr * \left(e^{\frac{x + Rsr * y}{nTr}} - 1 \right) - \frac{x + Rsr * y}{Rshr} - y == 0, \{x, 0, 0.7\}, \{y, 0, 9\} \right],$

AspectRatio $\rightarrow 3 / 2$, PlotRange $\rightarrow \{\{0, 0.7\}, \{0, 9\}\}$, Frame \rightarrow True, AspectRatio $\rightarrow 1 / 1$

Rscr

Rocr

Rsr

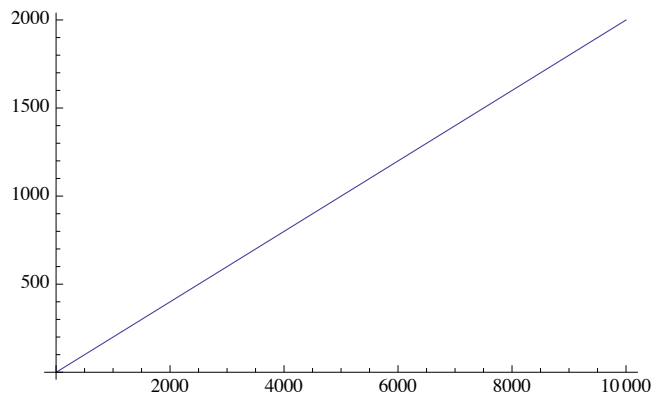
Rshr

nTr

IOr

Iphr

8.4



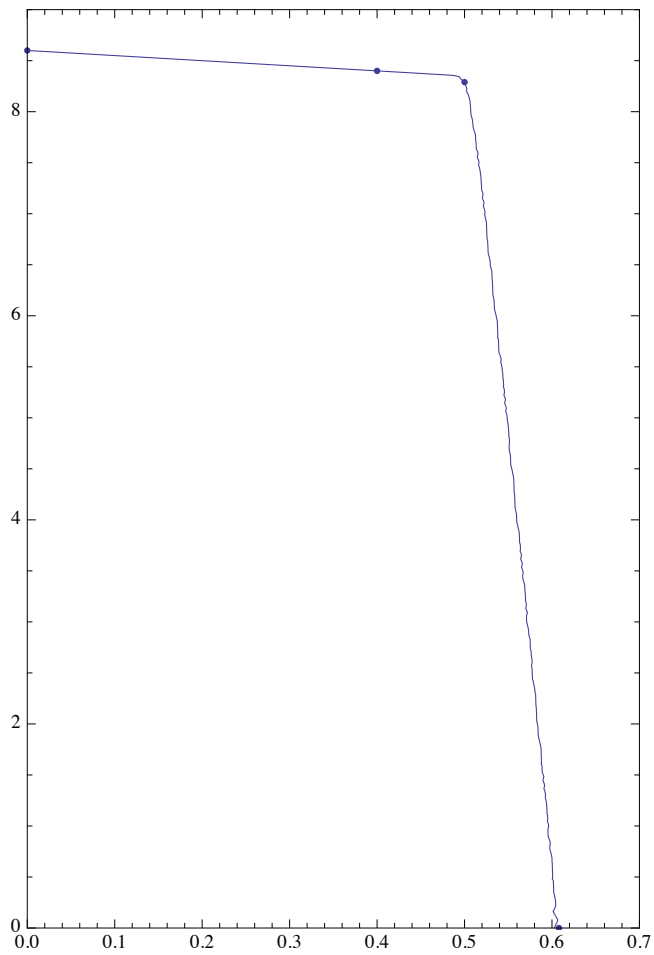
{148.256 → 2.}

{y → 8.6}

{y → 0.}

{y → 8.29}

{y → 8.4}



2.

0.0115859

0.0112219

1.98878

0.00303709

9.53371×10^{-87}

8.64853

```

Vocr := 0.608
Iscr := 7.665
Vmpr := 0.513
Impr := 7.174
Vsr := 0.4
Isr = 7.47

```

```

Rocr :=
1 / (((Rscr (Iscr - Impr) - Vmpr) ((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) Log[(Rscr (Iscr - Impr) -
Vmpr) / (Rscr Iscr - Vocr)] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr)) Impr)
((Rscr (Iscr - Impr) - Vmpr) ((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr)
Log[(Rscr (Iscr - Impr) - Vmpr) / (Rscr Iscr - Vocr)] +
(Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr))

```

```

Plot[Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)
e  $\frac{(Vsr-Vocr+Rocr Isr) (Rscr Iscr-Vocr) (Rscr Impr-Vmpr) - ((Vsr-Vocr) Impr-Vmpr Isr) (Rscr-Rocr) (Rscr (Iscr-Impr)-Vmpr)}{(Vmpr-Rocr Impr) (Rscr Iscr-Vocr) (Rscr (Iscr-Impr)-Vmpr)}$  - Vsr == 0, {Rscr, 0, 10}]

```

```

FindRoot[Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)
e  $\frac{(Vsr-Vocr+Rocr Isr) (Rscr Iscr-Vocr) (Rscr Impr-Vmpr) - ((Vsr-Vocr) Impr-Vmpr Isr) (Rscr-Rocr) (Rscr (Iscr-Impr)-Vmpr)}{(Vmpr-Rocr Impr) (Rscr Iscr-Vocr) (Rscr (Iscr-Impr)-Vmpr)}$  - Vsr == 0, {Rscr, 100}]

```

```
Rscr := 2.0000000000000617
```

```

Rocr :=
1 / (((Rscr (Iscr - Impr) - Vmpr) ((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) Log[(Rscr (Iscr - Impr) -
Vmpr) / (Rscr Iscr - Vocr)] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr)) Impr)
((Rscr (Iscr - Impr) - Vmpr) ((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr)
Log[(Rscr (Iscr - Impr) - Vmpr) / (Rscr Iscr - Vocr)] +
(Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr))

```

```

Rsr := (Rocr (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) -
Vmpr (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)) /
((Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - (Rscr - Rocr) Impr (Rscr (Iscr - Impr) - Vmpr))

```

```
Rshr := Rscr - Rsr
```

```
nTr := ((Rocr - Rsr) (Rscr Iscr - Vocr)) / (Rscr - Rocr)
(Rscr Iscr - Vocr)  $\frac{-Vocr (Rscr-Rocr)}{(Rocr-Rsr) (Rscr Iscr-Vocr)}$ 

```

```
I0r :=  $\frac{Rscr - Rsr}{Rscr Iscr} * e$ 
```

```
Iphr :=  $\frac{Rscr Iscr}{Rscr - Rsr} - I0r$ 
```

```
FindRoot[Iphr - I0r (e  $\frac{0+Rsr y}{nTr} - 1$ ) -  $\frac{0 + Rsr y}{Rshr} - y == 0, \{y, Iscr\}]$ 
```

```
FindRoot[Iphr - I0r (e  $\frac{Vocr+Rsr y}{nTr} - 1$ ) -  $\frac{Vocr + Rsr y}{Rshr} - y == 0, \{y, 0\}]$ 
```

```
FindRoot[Iphr - I0r (e  $\frac{Vmpr+Rsr y}{nTr} - 1$ ) -  $\frac{Vmpr + Rsr y}{Rshr} - y == 0, \{y, Impr\}]$ 
```

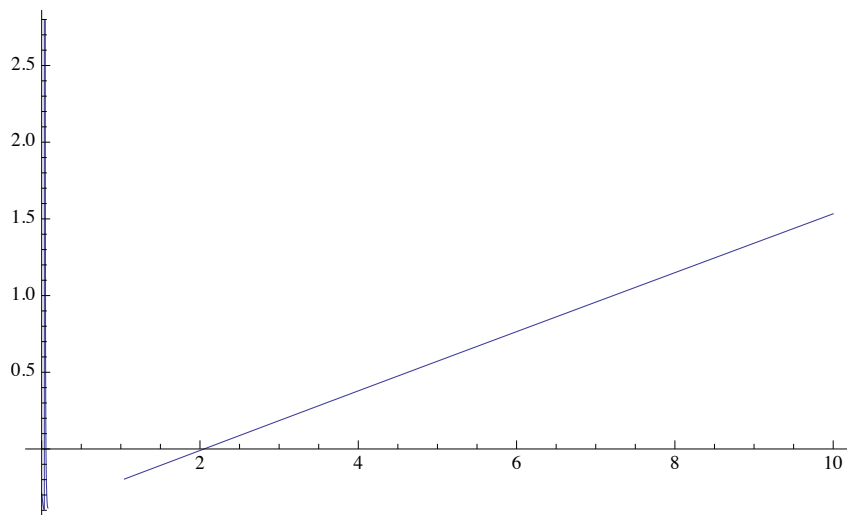
```
FindRoot[Iphr - I0r (e  $\frac{Vsr+Rsr y}{nTr} - 1$ ) -  $\frac{Vsr + Rsr y}{Rshr} - y == 0, \{y, Isr\}]$ 
```

```
Show[ListPlot[{{0, Iscr}, {Vmpr, Impr}, {Vsr, Isr}, {Vocr, 0}}],
```

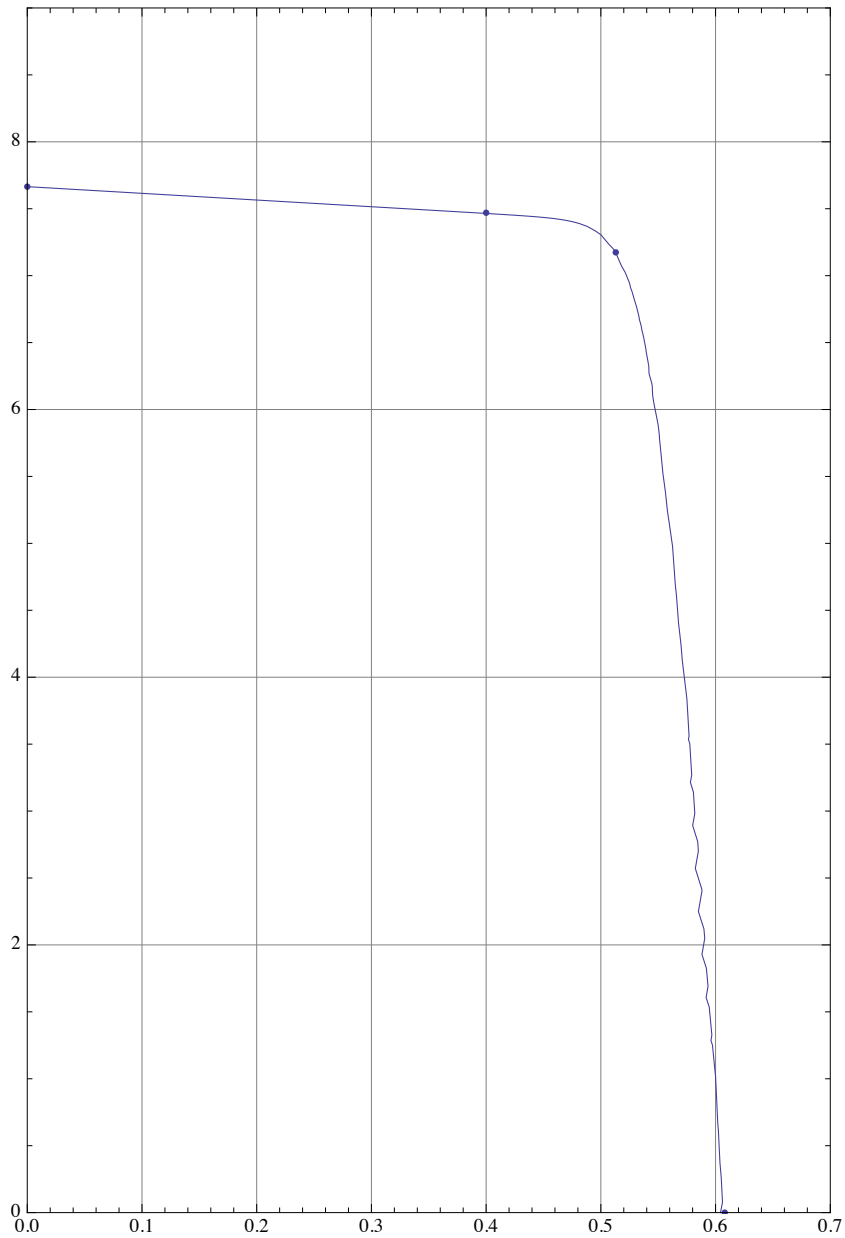
```
ContourPlot[Iphr - IOr * (e $\frac{x+Rsr*y}{nTr}$  - 1) -  $\frac{x + Rsr * y}{Rshr}$  - y == 0, {x, 0, 0.7}, {y, 0, 9}],
```

```
AspectRatio -> 3 / 2, PlotRange -> {{0, 0.7}, {0, 9}}, Frame -> True, GridLines -> Automatic]
```

```
Rscr  
Rocr  
Rsr  
Rshr  
nTr  
IOr  
Iphr  
7.47`
```



```
{2.00000000000000617` -> 2.0513074435394483`}  
{y -> 7.665`}  
{y -> 0.}`  
{y -> 7.174`}  
{y -> 7.464773527682432`}
```



2.0000000000000617`
0.007705492643114932`
0.005534218662608133`
1.9944657813374536`
0.016044563403143024`
2.5750587399315565`*^-16
7.686268745969884`

Applicazione della soluzione analitica approssimata del modello equivalente a cinque parametri della cella fotovoltaica al pannello SEM160 NTC

Vocr := 43
 Iscr := 4.7
 Vmpr := 34.9
 Impr := 4.3
 Vsr := 3.5
 Isr = 4.68

Rocr :=

$$\frac{1}{\left(\frac{(Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr}{(Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \right) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] - (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr)} \right)}$$
 - Vsr == 0, {Rscr, 0, 2000}

ans = Rscr /. FindRoot
$$\left[\frac{Rscr (Iscr - Isr) - (Rscr Iscr - Vocr)}{e^{\frac{(Vsr - Vocr + Rocr Isr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - ((Vsr - Vocr) Impr - Vmpr Isr) (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr)}{(Vmpr - Rocr Impr) (Rscr Iscr - Vocr) (Rscr (Iscr - Impr) - Vmpr)}}} - Vsr == 0, \{Rscr, 1000\} \right]$$

Rscr := ans

Rocr :=

$$\frac{1}{\left(\frac{(Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) + (Rscr Iscr - Vocr) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] + (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) \right) Impr}{(Rscr (Iscr - Impr) - Vmpr) \left((2 Vmpr - Vocr) Rscr Impr + Vmpr (Rscr Iscr - Vocr) \right) \log \left[\frac{Rscr (Iscr - Impr) - Vmpr}{Rscr Iscr - Vocr} \right] - (Vmpr - Vocr) (Rscr Iscr - Vocr) (Rscr Impr - Vmpr)} \right)}$$
 Rsr :=
$$\frac{(Rocr (Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - Vmpr (Rscr - Rocr) (Rscr (Iscr - Impr) - Vmpr))}{((Rscr Iscr - Vocr) (Rscr Impr - Vmpr) - (Rscr - Rocr) Impr (Rscr (Iscr - Impr) - Vmpr))}$$

Rshr := Rscr - Rsr

nTr :=
$$\frac{(Rocr - Rsr) (Rscr Iscr - Vocr)}{(Rscr Iscr - Vocr) \frac{-Vocr (Rscr - Rocr)}{(Rocr - Rsr) (Rscr Iscr - Vocr)}}$$

I0r :=
$$\frac{Rscr - Rsr}{Rscr Iscr}$$

Iphr :=
$$\frac{Rscr Iscr}{Rscr - Rsr} - I0r$$

FindRoot
$$\left[Iphr - I0r \left(e^{\frac{0 + Rsr y}{nTr}} - 1 \right) - \frac{0 + Rsr y}{Rshr} - y == 0, \{y, Iscr\} \right]$$

FindRoot
$$\left[Iphr - I0r \left(e^{\frac{Vocr + Rsr y}{nTr}} - 1 \right) - \frac{Vocr + Rsr y}{Rshr} - y == 0, \{y, 0\} \right]$$

FindRoot
$$\left[Iphr - I0r \left(e^{\frac{Vmpr + Rsr y}{nTr}} - 1 \right) - \frac{Vmpr + Rsr y}{Rshr} - y == 0, \{y, Impr\} \right]$$

FindRoot
$$\left[Iphr - I0r \left(e^{\frac{Vsr + Rsr y}{nTr}} - 1 \right) - \frac{Vsr + Rsr y}{Rshr} - y == 0, \{y, Isr\} \right]$$

Show [ListPlot[{ {0, 4.7}, {34, 4.4}, {43, 0} }, PlotStyle -> Black],

ContourPlot
$$\left[Iphr - I0r * \left(e^{\frac{x + Rsr * y}{nTr}} - 1 \right) - \frac{x + Rsr * y}{Rshr} - y == 0, \{x, 0, 45\}, \{y, 0, 5\}, ContourStyle -> Black \right]$$

Rscr

Rocr

Rsr

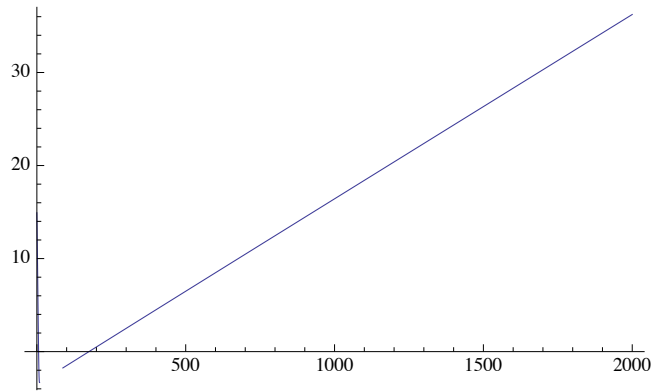
Rshr

nTr

I0r

Iphr

4.68



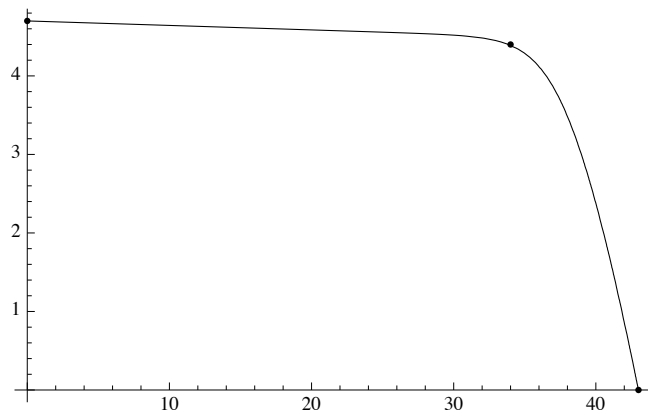
175.

{y → 4.7}

{y → 0.}

{y → 4.3}

{y → 4.68}



175.

1.11427

0.769575

174.23

1.5452

3.6739×10^{-12}

4.72076

A5 Correlazione della Isc secondo Celik et al

```
Data = Extract[Import["Desktop/Fit Isc/0.01ohm kyo copia.xls"], 1]
Data = Drop[Data, 1]
Iscr = 8.09
GR = 1000
TR = 25
TP = Take[Data, All, {1}]
G = Take[Data, All, {2}]
Isc = Take[Data, All, {3}] / 1000
```

$$Isc1 = Iscr \left(\frac{G}{GR} \right) + 3.18 \times 10^{-3} (TP - TR)$$

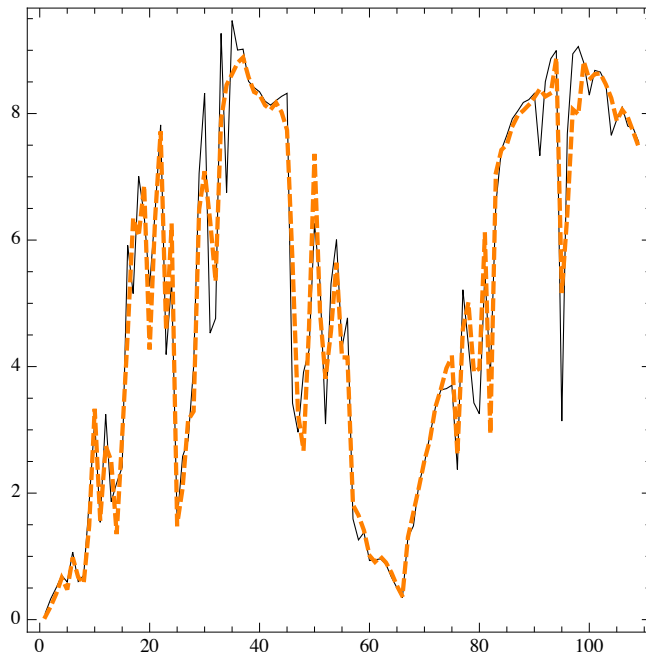
```
Show[ListLinePlot[Transpose[Isc], PlotStyle -> Black],
ListLinePlot[Transpose[Isc1], PlotStyle -> {Dashed, Thick, Orange}],
Frame -> True, AspectRatio -> 1 / 1]
```

$$ERR = \sqrt{\text{Mean}[(Isc - Isc1)^2]}$$

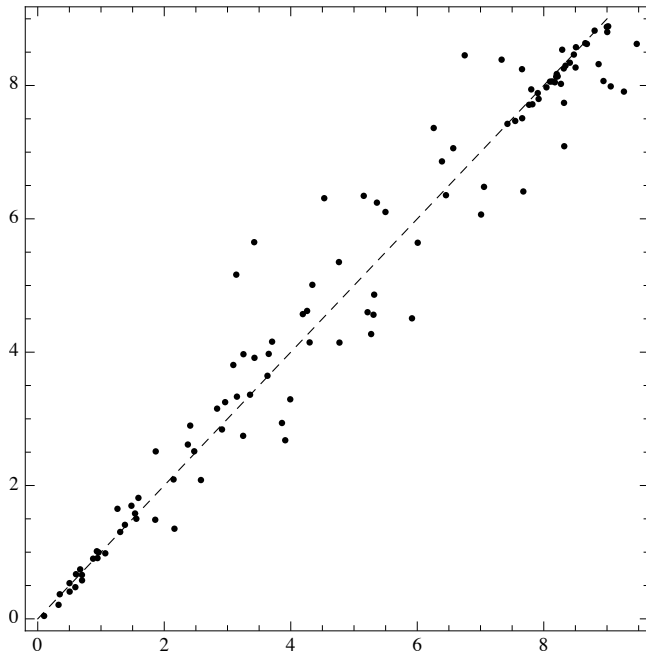
```
ans = Transpose[ArrayFlatten[{{Flatten[Isc], Flatten[Isc1]}]}]
```

```
Show[ListPlot[ans, PlotStyle -> {Dashed, Black}],
Plot[x, {x, 0, 9}], PlotStyle -> {Dashed, Black}], Frame -> True, AspectRatio -> 1 / 1]
```

```
Correlation[Isc, Isc1]
```



```
{0.631295}
```



{{0.976704}}

Correlazione della Voc secondo la relazione (6.1 .6)

Vocr := 29.2

nTr := 0.8792254480255973`

TR := 25

GR := 1000

DTA := {23.53333333, 23.6, 23.43333333, 23.26666667, 23.1, 23.03333333, 22.96666667, 22.9, 22.8, 22.7, 22.6, 22.5, 22.4, 22.3, 22.1, 21.9, 21.7, 21.66666667, 21.63333333, 21.6, 21.63333333, 21.66666667, 21.7, 21.73333333, 21.76666667, 21.8, 21.8, 21.8, 21.8, 21.16666667, 20.53333333, 19.9, 19.13333333, 18.36666667, 17.6, 17.66666667, 17.73333333, 17.8, 17.73333333, 17.66666667, 17.6, 17.46666667, 17.33333333, 17.2, 17.1, 17, 16.9, 17, 17.1, 17.2, 17.33333333, 17.46666667, 17.6}

DTP := {24.467, 23.1337, 23.9677, 29.5677, 25.568, 26.767, 28.567, 30.333, 29.133, 28.433, 30.133, 28.700, 39.900, 30.133, 29.167, 36.233, 29.633, 27.333, 32.367, 28.600, 33.567, 33.100, 29.567, 29.500, 25.600, 27.900, 31.733, 36.233, 29.200, 28.867, 29.033, 27.567, 27.933, 29.333, 31.067, 33.633, 30.233, 28.700, 33.867, 33.00, 29.800, 29.467, 28.367, 36.433, 31.900, 33.267, 34.700, 32.200, 31.167, 25.067, 21.300, 22.333, 25.867}

DGP := {169.772, 138.607, 190.483, 277.919, 183.466, 256.450, 301.508, 312.091, 271.454, 263.524, 281.492, 348.291, 686.646, 198.369, 234.830, 461.553, 269.451, 225.320, 419.967, 287.180, 463.265, 393.923, 229.825, 259.767, 102.187, 178.619, 324.754, 486.277, 196.400, 232.096, 233.996, 162.452, 190.492, 262.403, 302.440, 368.188, 207.264, 213.918, 364.759, 295.176, 182.768, 266.668, 708.068, 455.920, 382.971, 358.611, 393.531, 243.531, 262.023, 207.396, 68.056, 139.980, 211.326}

DVP := {27.043, 26.545, 27.125, 27.166, 26.636, 27.373, 26.971, 27.162, 27.002, 27.194, 27.071, 27.173, 27.095, 26.534, 26.742, 27.159, 26.863, 26.871, 27.275, 26.768, 27.260, 27.313, 26.737, 26.659, 26.018, 26.782, 27.429, 27.226, 26.541, 27.002, 26.958, 26.536, 26.791, 27.112, 27.141, 27.275, 26.488, 26.577, 27.106, 26.683, 26.219, 26.551, 27.628, 26.585, 27.124, 26.975, 27.035, 26.418, 26.734, 26.516, 25.574, 26.381, 26.729}

DVOC := {}

$$VK = \sqrt[4]{nTr^3 \frac{\text{Mean}[DVP - Vocr] - \text{Mean}[1.09 \times 10^{-1} (DTP - TR)]}{\text{Mean}\left[\text{Log}\left[\frac{DGP}{GR}\right]\right]}}$$

For[h = 1, h ≤ 53, h++,

TA = Extract[DTA, h];

TC = Extract[DTP, h];

G = Extract[DGP, h];

$$nT = nTr \left(\frac{TC + 273.15}{TR + 273.15} \right);$$

$$ans = Vocr - 1.09 \times 10^{-1} (TC - TR) + \frac{1}{nTr^3} \text{Log}\left[\frac{G}{GR}\right];$$

DVOC = Append[DVOC, ans]

]

$$\sigma = \sqrt{\text{Mean}[(DVOC - DVP)^2]}$$

Correlation[DVOC, DVP]

Show[ListLinePlot[{DVP}, PlotStyle → {Black}],

ListLinePlot[{DVOC}, PlotStyle → {Dashed, Thick, Orange}],

Frame → True, AspectRatio → 1 / 1]

m = Transpose[ArrayFlatten[{DVOC, DVP}]]

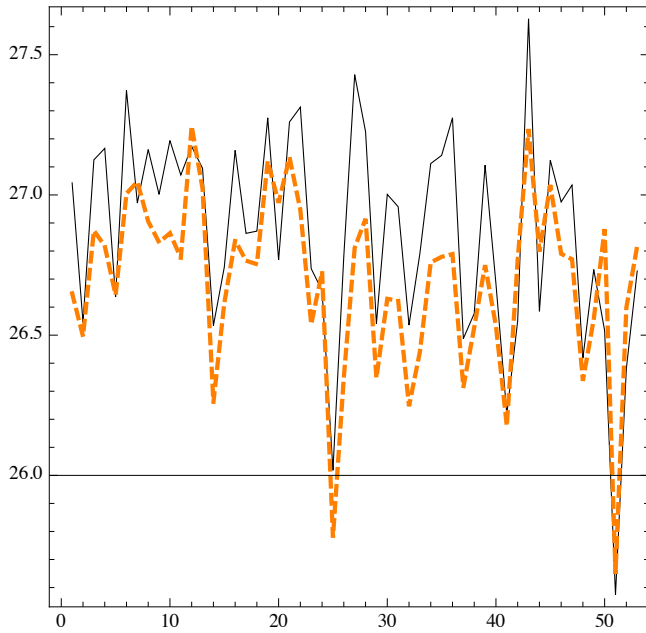
Show[ListPlot[m, PlotStyle → Black],

Plot[x, {x, 25, 28}, PlotStyle → {Dashed, Black}], Frame → True, AspectRatio → 1 / 1]

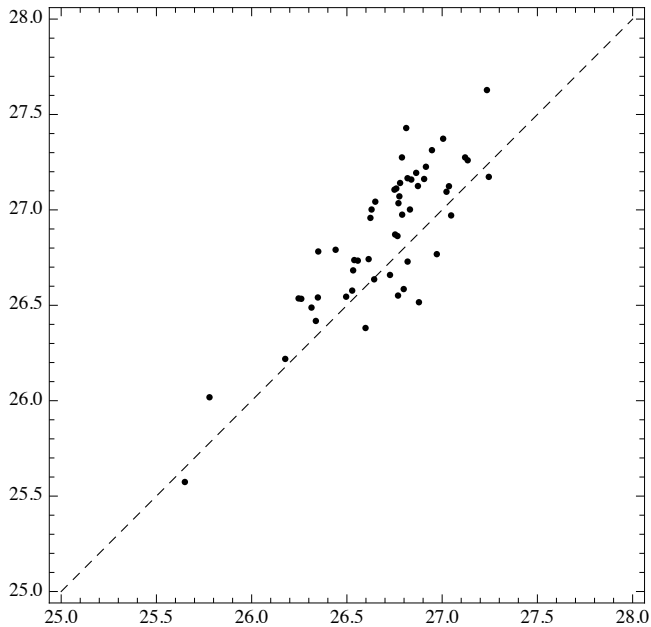
1.0979

0.265776

0.83776



```
{ {26.6491, 27.043}, {26.496, 26.545}, {26.8728, 27.125},
  {26.8182, 27.166}, {26.6432, 26.636}, {27.0052, 27.373},
  {27.0472, 26.971}, {26.9054, 27.162}, {26.831, 27.002}, {26.8637, 27.194},
  {26.7754, 27.071}, {27.2449, 27.173}, {27.0228, 27.095},
  {26.2605, 26.534}, {26.614, 26.742}, {26.8381, 27.159}, {26.7656, 26.863},
  {26.7531, 26.871}, {27.1205, 27.275}, {26.9719, 26.768}, {27.1341, 27.26},
  {26.9464, 27.313}, {26.5388, 26.737}, {26.7262, 26.659}, {25.7787, 26.018},
  {26.3496, 26.782}, {26.8114, 27.429}, {26.9148, 27.226}, {26.3475, 26.541},
  {26.6295, 27.002}, {26.6234, 26.958}, {26.2463, 26.536}, {26.4407, 26.791},
  {26.7593, 27.112}, {26.7792, 27.141}, {26.7889, 27.275}, {26.3141, 26.488},
  {26.5277, 26.577}, {26.7497, 27.106}, {26.5328, 26.683}, {26.1763, 26.219},
  {26.7684, 26.551}, {27.2351, 27.628}, {26.7982, 26.585}, {27.0358, 27.124},
  {26.7901, 26.975}, {26.7706, 27.035}, {26.337, 26.418}, {26.5573, 26.734},
  {26.8782, 26.516}, {25.6493, 25.574}, {26.5978, 26.381}, {26.8186, 26.729}}
```



Correlazione della Voc proposta da Celik et al - relazione (4.3 .10)

Vocr := 29.2

Iscr := 8.09

Vmpr := 23.6

Impr := 7.42

$$Rso := \frac{29.2 - 28.279}{1.996}$$

$$Rsho := \frac{5.102}{8.09 - 8.011}$$

DVOC1 := {}

For[h = 1, h ≤ 53, h++,

T = Extract[DTP, h];

G = Extract[DGP, h];

$$Vt := \frac{1.380658 \cdot 10^{-23} (T + 273.15)}{1.6021773 \cdot 10^{-19}};$$

m :=

$$\left(Vmpr + Impr Rso - Vocr \right) / \left(Vt \left(\log \left[Iscr - \frac{Vmpr}{Rsho} - Impr \right] - \log \left[Iscr - \frac{Vocr}{Rsho} \right] + \frac{Impr}{Iscr - \frac{Vocr}{Rsho}} \right) \right);$$

$$ans = Vocr + m Vt \log \left[\frac{G}{1000} \right] - 1.09 \cdot 10^{-1} (T - 25);$$

DVOC1 = Append[DVOC1, ans]

Show[ListLinePlot[{DVP}, PlotStyle → Black],
ListLinePlot[{DVOC1}, PlotStyle → {Dashed, Thick, Orange}],
Frame → True, AspectRatio → 1 / 1]

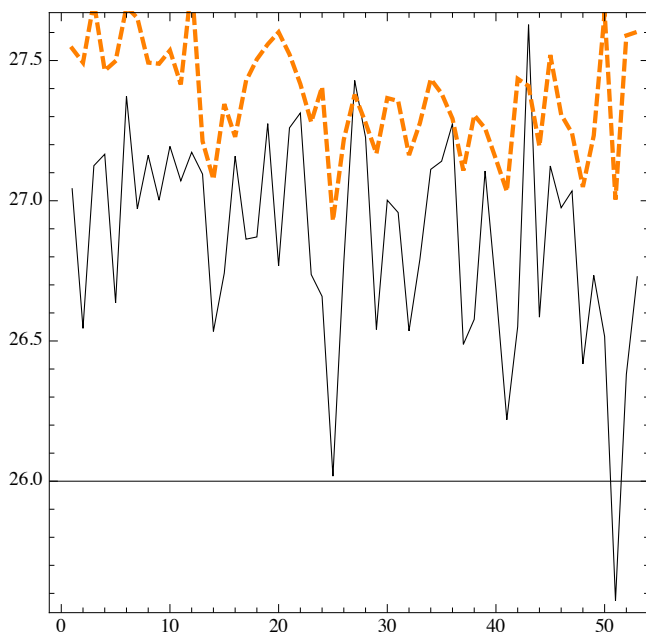
$$\sigma = \sqrt{\text{Mean}[(DVOC1 - DVP)^2]}$$

Correlation[DVOC1, DVP]

n = Transpose[ArrayFlatten[{DVOC1, DVP}]]

Show[ListPlot[n, PlotStyle → Black],

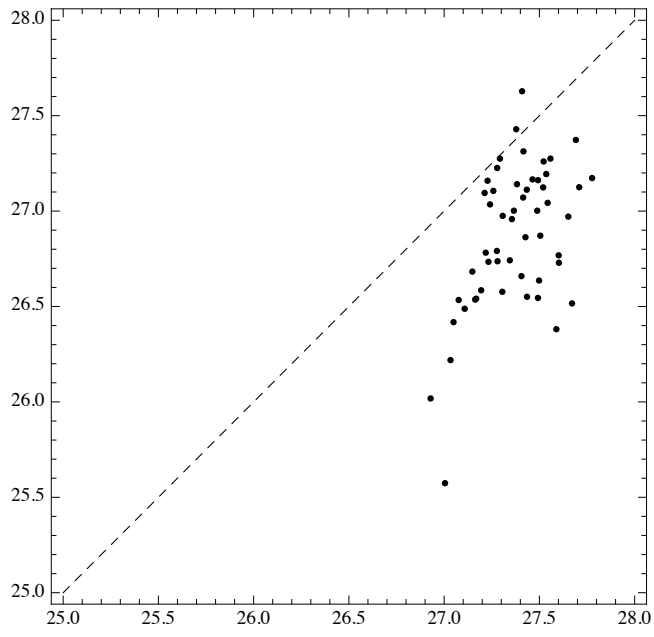
Plot[x, {x, 25, 28}, PlotStyle → {Dashed, Black}], Frame → True, AspectRatio → 1 / 1]



0.598954

0.514612

```
{ {27.5433, 27.043}, {27.4925, 26.545}, {27.709, 27.125},  
  {27.4639, 27.166}, {27.4983, 26.636}, {27.6915, 27.373},  
  {27.6518, 26.971}, {27.4927, 27.162}, {27.4886, 27.002},  
  {27.5362, 27.194}, {27.4147, 27.071}, {27.7768, 27.173}, {27.2124, 27.095},  
  {27.0762, 26.534}, {27.3447, 26.742}, {27.2279, 27.159}, {27.4269, 26.863},  
  {27.5046, 26.871}, {27.558, 27.275}, {27.6011, 26.768}, {27.5221, 27.26},  
  {27.4162, 27.313}, {27.2803, 26.737}, {27.406, 26.659}, {26.9289, 26.018},  
  {27.2182, 26.782}, {27.3785, 27.429}, {27.2784, 27.226}, {27.1683, 26.541},  
  {27.3661, 27.002}, {27.3559, 26.958}, {27.1628, 26.536}, {27.2769, 26.791},  
  {27.434, 27.112}, {27.3823, 27.141}, {27.2928, 27.275}, {27.1078, 26.488},  
  {27.3054, 26.577}, {27.2582, 27.106}, {27.1481, 26.683}, {27.0333, 26.219},  
  {27.4349, 26.551}, {27.4092, 27.628}, {27.1943, 26.585}, {27.5198, 27.124},  
  {27.3072, 26.975}, {27.2409, 27.035}, {27.0493, 26.418}, {27.2327, 26.734},  
  {27.6715, 26.516}, {27.0045, 25.574}, {27.5893, 26.381}, {27.6024, 26.729}}
```



Validazione del modello proposto - Pannello KyoceraKC175 - GHT2 RL = 1 Ω

```
Vocr := 29.2
Iscr := 8.09
Rsr := 0.36374680068318227
Rshr := 64.03917551490149
Rscr := 64.40292231558468
nTr := 0.8994957428538155
TR := 298.15
TN := 320.15
GR := 1000
GN := 800

DTP := {26.533, 31.3222, 36.589, 43.178, 46.75555556,
52.078, 52.056, 48.733, 49.033, 50.311, 52.233, 54.456, 53.256, 50.7,
53.4, 50.511, 48.711, 45.878, 43.589, 40.4, 37.511, 33.289, 31.244}
DGP := {108.733, 202.6, 333.4, 474.2, 586.8, 698.933, 793.867, 876.4,
938.867, 983.467, 1015.8, 1014.133, 989.4, 962.267, 913.533,
844.067, 755.867, 635.333, 538.533, 406.067, 278.267, 124, 73.133}
DVP := {0.906514, 1.644321, 2.836609, 3.897891, 4.806863, 5.728975, 6.447894,
7.10743, 7.576352, 7.929135, 8.131268, 8.107199, 7.910413, 7.688874, 7.278713,
6.697642, 5.962396, 4.777407, 4.073374, 3.061477, 1.85741, 0.883089, 0.481024}
DRL := {1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1}
DP := DVP ^ 2 / DRL
CP := {}
```

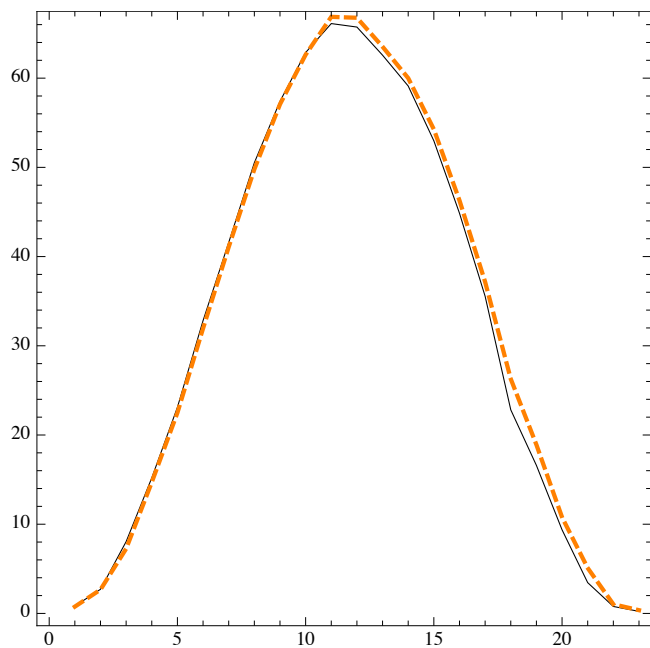
```
For[h = 1, h ≤ 23, h++,
TC = Extract[DTP, h] + 273.15;
G = Extract[DGP, h];
R = Extract[DRL, h];
V = Extract[DVP, h];
nT = nTr (TC / TR);
Rs = Rsr (GR TR / TC G);
Rsc = Rscr;

Voc = Vocr - 1.09 10-1 (TC - TR) + Log[G / GR] / nTr3;
Isc = Iscr (G / GR) + 3.18 10-3 (TC - TR);
ans = y /. FindRoot[Isc - R y / Rsc - (Isc - Voc / Rsc) e(R y + Rs y - Voc) / nT - y == 0, {y, 1}];
CP = Append[CP, ans ^ 2]
```

```
Show[ListLinePlot[{DP}, PlotStyle → Black],
ListLinePlot[{CP}, PlotStyle → {Dashed, Thick, Orange}],
Frame → True, AspectRatio → 1 / 1]
```

$$\sigma = \sqrt{\text{Mean}[(CP - DP)^2]}$$

Correlation[CP, DP]



1.2276
0.998933

Validazione sperimentale del modello Celik et al. - Pannello KyoceraKC175 - GHT2 RL = 1 Ω

Vocr := 29.2

Iscr := 8.09

Vmpr := 23.6

Impr := 7.42

Rso := $\frac{29.2-28.279}{1.996}$

Rsho := $\frac{5.102}{8.09-8.011}$

DP := DVP² / DRL

PC1 := {}

For[h = 1, h ≤ 23, h++,

T = Extract[DTP, h] + 273.15;

G = Extract[DGP, h];

R = Extract[DRL, h];

V = Extract[DVP, h];

Vt := $\frac{1.380658 \cdot 10^{-23} T}{1.6021773 \cdot 10^{-19}}$;

m := $(Vmpr + Impr Rso - Vocr) / \left(Vt \left(\text{Log} \left[Iscr - \frac{Vmpr}{Rsho} - Impr \right] - \text{Log} \left[Iscr - \frac{Vocr}{Rsho} \right] + \frac{Impr}{Iscr - \frac{Vocr}{Rsho}} \right) \right)$;

Voc = Vocr + m Vt Log $\left[\frac{G}{1000} \right] - 1.09 \cdot 10^{-1} (T - 298.15)$;

Isc = $\frac{Iscr G}{1000} + 3.18 \cdot 10^{-3} (T - 298.15)$;

Rs = Rso - $\frac{m Vt}{\left(Iscr - \frac{Vocr}{Rsho} \right)}$;

IO := $\left(Iscr - \frac{Vocr}{Rsho} \right) e^{\left(\frac{-Vocr}{m Vt} \right)}$;

IL := $Isc \left(1 + \frac{Rs}{Rsho} \right) + IO \left(e^{\frac{Isc Rs}{m Vt}} - 1 \right)$;

ans = y /. FindRoot $\left[IL - IO \left(e^{\frac{V+Rs y}{m Vt}} - 1 \right) - \frac{V+Rs y}{Rsho} - y == 0, \{y, 1.5\} \right]$;

PC1 = Append[PC1, ans²]

$\sigma = \sqrt{\text{Mean}[(PC1 - DP)^2]}$

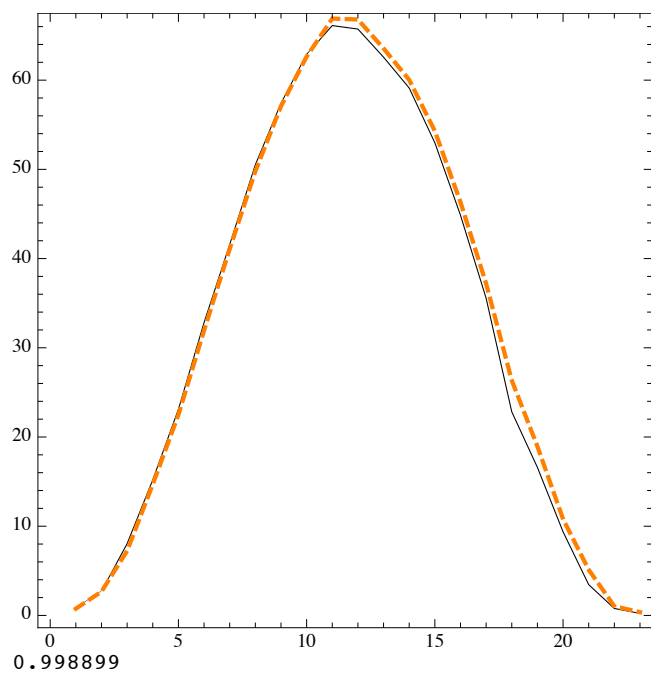
Show[ListLinePlot[{DP}, PlotStyle → Black], ListLinePlot[{CP}, PlotStyle → White],

ListLinePlot[{PC1}, PlotStyle → {Dashed, Thick, Orange}],

Frame → True, AspectRatio → 1 / 1]

Correlation[DP, PC1]

1.2507



come sopra RL = 5 Ω

Vocr := 29.2

Iscr := 8.09

Rsr := 0.36374680068318227

Rscr := 64.40292231558468

nTr := 0.8994957428538155

TR := 298.15

TN := 320.15

GR := 1000

GN := 800

DTP := {25.044, 29.056, 32.944, 35.833, 39.633, 41.544, 42.389,

45.189, 45.567, 46.256, 48.911, 47.5, 46.489, 46.356, 45.889, 42.789,

43.156, 41.233, 41.233, 37.022, 32.756, 30.889, 30.122, 29.778, 28.144}

DGP := {70.733, 152, 252.8, 369.867, 478.2, 586.933, 673.933, 762.267,

821.2, 875.6, 905.133, 927.8, 946.133, 935, 903.533, 858.333, 798,

720.267, 627.133, 435, 264.867, 186.4, 165.733, 125.333, 67.733}

DVP := {2.703364, 5.813323, 9.983171, 14.68671, 18.9843, 21.78375, 22.96823, 23.52657,

23.85362, 23.96677, 24.01151, 24.23062, 24.28645, 24.2695, 24.17883, 24.09941, 23.8097,

23.35642, 22.11734, 15.19343, 10.31103, 7.486032, 6.146443, 4.112945, 2.34661}

DRL := {5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5}

DP := DVP^2 / DRL

GM = Max[DGP]

Gm = Min[DGP]

PM = Max[DP]

CP := {}

For[h = 1, h ≤ 25, h++,

TC = Extract[DTP, h] + 273.15;

G = Extract[DGP, h];

R = Extract[DRL, h];

V = Extract[DVP, h];

nT = nTr $\left(\frac{TC}{TR}\right)$;

Rs = Rsr $\left(\frac{GR TR}{TC G}\right)$;

Rsc = Rscr;

Voc = Vocr - 1.09 10⁻¹ (TC - TR) + $\frac{\text{Log}\left[\frac{G}{GR}\right]}{nTr^3}$;

Isc = Iscr $\left(\frac{G}{GR}\right)$ + 3.18 10⁻³ (TC - TR);

T = Extract[DTP, h] + 273.15;

G = Extract[DGP, h];

R = Extract[DRL, h];

V = Extract[DVP, h];

ans = y /. FindRoot $\left[\text{Isc} - \frac{R y}{Rsc} - \left(\text{Isc} - \frac{\text{Voc}}{Rsc} \right) e^{\frac{R y + Rs y - \text{Voc}}{nT}} - y = 0, \{y, 1\} \right]$;

CP = Append[CP, ans^2 * 5]

Show[ListLinePlot[{DP}, PlotStyle → Black],

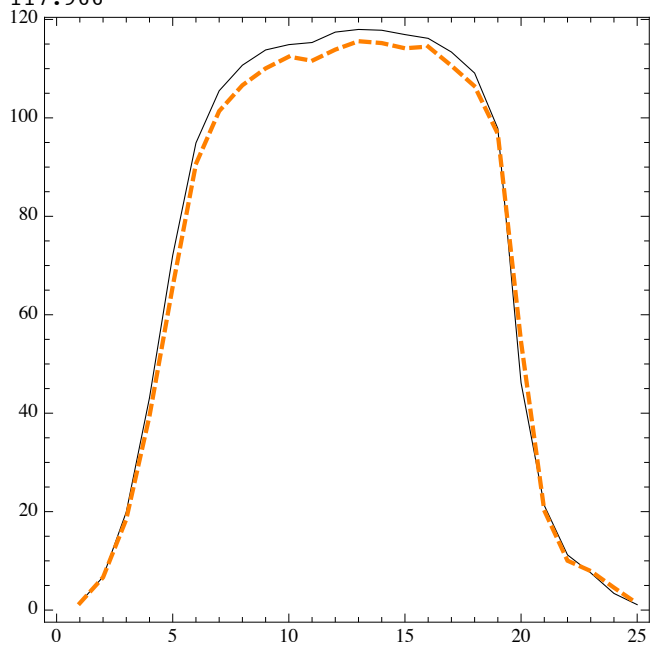
ListLinePlot[{CP}, PlotStyle → {Dashed, Thick, Orange}],

Frame → True, AspectRatio → 1 / 1]

$\sigma = \sqrt{\text{Mean}[(CP - DP)^2]}$

Correlation[CP, DP]

946.133
67.733
117.966



3.26175
0.998749

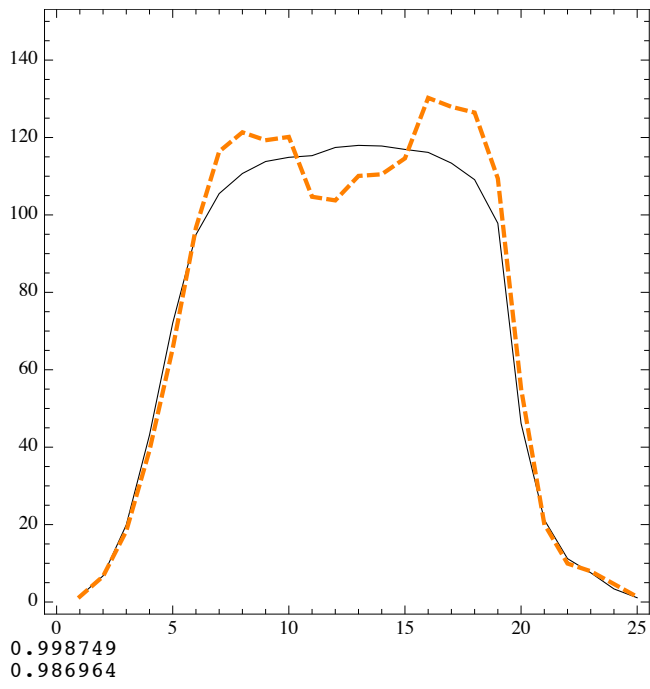
```

Vocr := 29.2
Iscr := 8.09
Vmpr := 23.6
Impr := 7.42
Rso :=  $\frac{29.2 - 28.279}{1.996}$ 
Rsho :=  $\frac{5.102}{8.09 - 8.011}$ 
DP := DVP^2 / DRL
CP1 := {}
For[h = 1, h ≤ 25, h++,
  T = Extract[DTP, h] + 273.15;
  G = Extract[DGP, h];
  R = Extract[DRL, h];
  V = Extract[DVP, h];
  Vt :=  $\frac{1.380658 \cdot 10^{-23} \cdot T}{1.6021773 \cdot 10^{-19}}$ ;

  m :=  $(Vmpr + Impr Rso - Vocr) / \left( Vt \left( \text{Log} \left[ Iscr - \frac{Vmpr}{Rsho} - Impr \right] - \text{Log} \left[ Iscr - \frac{Vocr}{Rsho} \right] + \frac{Impr}{Iscr - \frac{Vocr}{Rsho}} \right) \right)$ ;

  Voc = Vocr + m Vt Log  $\left[ \frac{G}{1000} \right] - 1.09 \cdot 10^{-1} (T - 298.15)$ ;
  Isc =  $\frac{Iscr G}{1000} + 3.18 \cdot 10^{-3} (T - 298.15)$ ;
  Rs =  $Rso - \frac{m Vt}{\left( Iscr - \frac{Vocr}{Rsho} \right)}$ ;
  IO :=  $\left( Iscr - \frac{Vocr}{Rsho} \right) e^{\left( \frac{-Voc}{m Vt} \right)}$ ;
  IL :=  $Isc \left( 1 + \frac{Rs}{Rsho} \right) + IO \left( e^{\frac{Isc Rs}{m Vt}} - 1 \right)$ ;
  ans = y /. FindRoot  $\left[ IL - IO \left( e^{\frac{V+Rs y}{m Vt}} - 1 \right) - \frac{V+Rs y}{Rsho} - y = 0, \{y, 2\} \right]$ ;
  CP1 = Append[CP1, ans^2 * 5]
]
σ =  $\sqrt{\text{Mean}[(CP1 - DP)^2]}$ 
Show[ListLinePlot[{DP}, PlotStyle → Black],
  ListLinePlot[{CP1}, PlotStyle → {Dashed, Thick, Orange}],
  PlotRange → {0, 150}, Frame → True, AspectRatio → 1 / 1]
Correlation[DP, CP1]
Correlation[DP, CP1]
8.25943

```



```

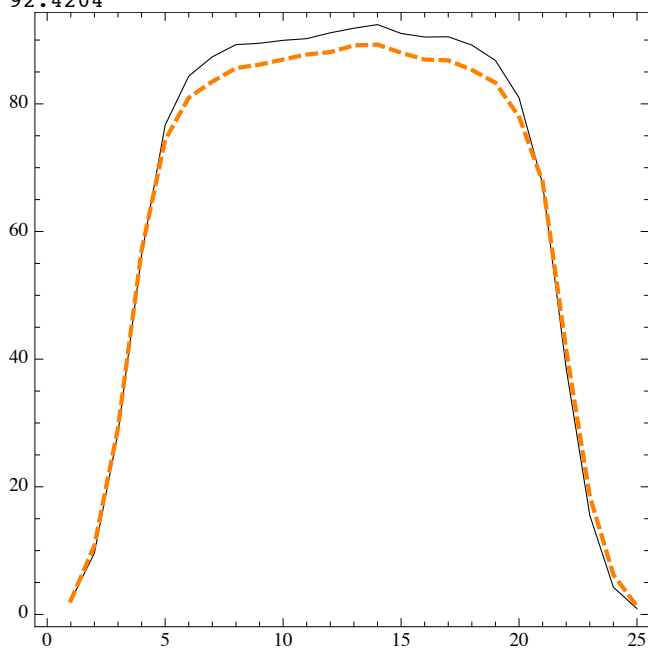
come sopra RL = 7 Ω
Vocr := 29.2
Iscr := 8.09
Rsr := 0.36374680068318227
Rscr := 64.40292231558468
nTr := 0.8994957428538155
TR := 298.15
TN := 320.15
GR := 1000
GN := 800

DTP := {23.3, 26.667, 31.033, 34.578, 37.122, 39.422, 42.811,
  44.311, 46.556, 47.522, 48.022, 48.333, 47.2, 46.622, 47.244, 46.822,
  44.444, 42.733, 40.122, 38.767, 36.244, 33.844, 31.678, 28.844, 26.456}
DGP := {77.2, 169.533, 277.333, 390.533, 504.267, 614.467, 712.267, 796.533,
  863.867, 917.933, 963.4, 989.2, 1000.067, 988.2, 952.333, 899.067, 837.867,
  758.467, 668.667, 560.2, 445.867, 330.133, 220.4, 127.733, 58.267}
DVP := {3.887906, 8.200033, 14.10965, 19.84017, 23.16647, 24.29803, 24.73124, 24.99899,
  25.02944, 25.0937, 25.13039, 25.25754, 25.35633, 25.43507, 25.24368, 25.16563, 25.17126,
  24.9892, 24.64837, 23.80647, 21.72864, 16.42382, 10.42606, 5.461016, 2.525576}
DRL := {7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7}
DP := DVP^2 / DRL
CP := {}
GM = Max[DGP]
Gm = Min[DGP]
TM = Max[DTP]
Tm = Min[DTP]
PMax = Max[DP]
For[h = 1, h ≤ 25, h++,
  TC = Extract[DTP, h] + 273.15;
  G = Extract[DGP, h];
  R = Extract[DRL, h];
  V = Extract[DVP, h];
  nT = nTr (TC / TR);
  Rs = Rsr (GR TR / TC G);
  Rsc = Rscr;
  Voc = Vocr - 1.09 10^-1 (TC - TR) + Log[G / GR] / nTr^3;
  Isc = Iscr (G / GR) + 3.18 10^-3 (TC - TR);
  ans = y /. FindRoot[Isc - R y / Rsc - (Isc - Voc / Rsc) e^(R y + Rs y - Voc / nT) - y == 0, {y, 1}];
  CP = Append[CP, ans^2 * 7] ]

Show[ListLinePlot[{DP}, PlotStyle → Black],
  ListLinePlot[{CP}, PlotStyle → {Dashed, Thick, Orange}],
  Frame → True, AspectRatio → 1 / 1]
σ = √Mean[(CP - DP)^2]
Correlation[CP, DP]
1000.07
58.267

```

48.333
23.3
92.4204



2.78243
0.999373

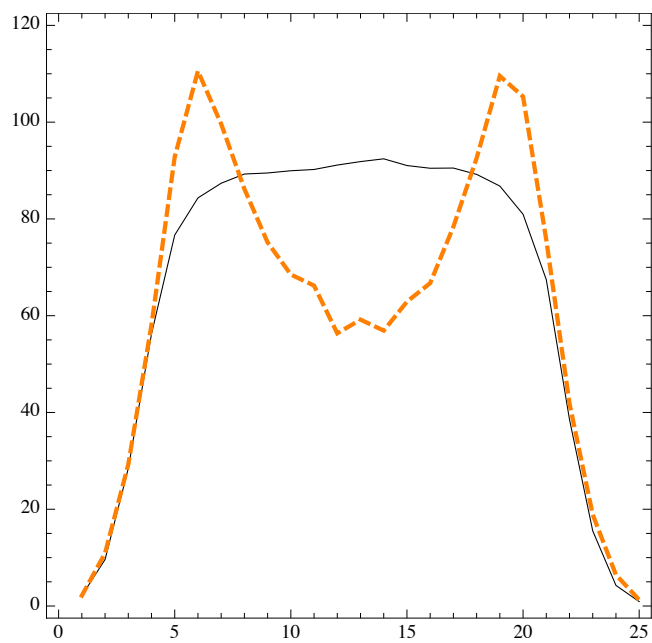
```

Vocr := 29.2
Iscr := 8.09
Vmpr := 23.6
Impr := 7.42
Rso :=  $\frac{29.2 - 28.279}{1.996}$ 
Rsho :=  $\frac{5.102}{8.09 - 8.011}$ 
DP := DVP^2 / DRL
CP1 := {}
For[h = 1, h ≤ 25, h++,
  T = Extract[DTP, h] + 273.15;
  G = Extract[DGP, h];
  R = Extract[DRL, h];
  V = Extract[DVP, h];
  Vt :=  $\frac{1.380658 \cdot 10^{-23} \cdot T}{1.6021773 \cdot 10^{-19}}$ ;

  m :=  $(Vmpr + Impr Rso - Vocr) / \left( Vt \left( \text{Log} \left[ Iscr - \frac{Vmpr}{Rsho} - Impr \right] - \text{Log} \left[ Iscr - \frac{Vocr}{Rsho} \right] + \frac{Impr}{Iscr - \frac{Vocr}{Rsho}} \right) \right)$ ;

  Voc = Vocr + m Vt Log  $\left[ \frac{G}{1000} \right] - 1.09 \cdot 10^{-1} (T - 298.15)$ ;
  Isc =  $\frac{Iscr G}{1000} + 3.18 \cdot 10^{-3} (T - 298.15)$ ;
  Rs =  $Rso - \frac{m Vt}{\left( Iscr - \frac{Vocr}{Rsho} \right)}$ ;
  IO :=  $\left( Iscr - \frac{Vocr}{Rsho} \right) e^{\left( \frac{-Voc}{m Vt} \right)}$ ;
  IL :=  $Isc \left( 1 + \frac{Rs}{Rsho} \right) + IO \left( e^{\frac{Isc Rs}{m Vt}} - 1 \right)$ ;
  ans = y /. FindRoot  $\left[ IL - IO \left( e^{\frac{V+Rs y}{m Vt}} - 1 \right) - \frac{V+Rs y}{Rsho} - y == 0, \{y, 2\} \right]$ ;
  CP1 = Append[CP1, ans^2 * 7] ]
σ =  $\sqrt{\text{Mean}[(CP1 - DP)^2]}$ 
Show[ListLinePlot[{DP}, PlotStyle → Black],
  ListLinePlot[{CP1}, PlotStyle → {Dashed, Thick, Orange}],
  Frame → True, PlotRange → {0, 120}, AspectRatio → 1 / 1]
18.5583

```




```

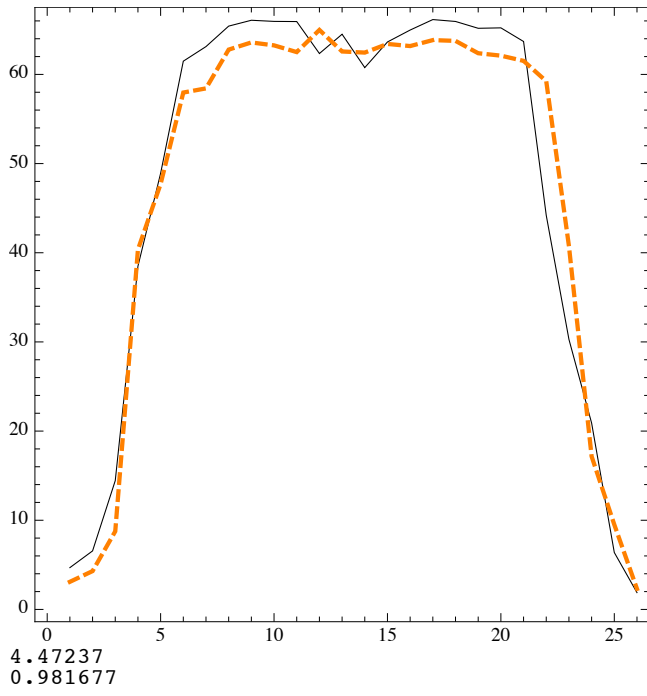
come sopra RL = 10 Ω
Vocr := 29.2
Iscr := 8.09
Rsr := 0.36374680068318227
Rscr := 64.40292231558468
nTr := 0.8994957428538155
TR := 298.15
TN := 320.15
GR := 1000
GN := 800

DTP := {22.6, 24.744, 26.989, 30.8, 32.744, 36.667, 37.433, 41.211,
        42.644, 46.144, 46.678, 47.278, 52.333, 53.189, 44.511, 50.433, 47.944,
        46.333, 46.033, 42.444, 38.478, 34.711, 30.544, 30.122, 27.733, 26.122}
DGP := {80.4, 93.733, 132.867, 286.867, 325.6, 476.6, 494.667, 689.333,
        758.467, 835.2, 807.533, 987.733, 1002, 1027.067, 798.133, 974.067, 930.6,
        871.2, 783.067, 686.2, 593.467, 485.667, 288.533, 185.067, 138.2, 68.133}
DVP := {6.846250848, 8.100668755, 12.01707073, 19.61990814, 22.11550407, 24.79588538,
        25.12384232, 25.57659655, 25.70466883, 25.67991941, 25.67633092, 24.96833876, 25.39795841,
        24.65022368, 25.22657064, 25.49024336, 25.7196236, 25.67848934, 25.52887771, 25.53837581,
        25.23717879, 21.02275819, 17.40362998, 14.45624584, 7.989345757, 4.340692578}
DRL := {10, 10, 10, 10, 10, 10, 10, 10, 10, 10, 10, 10, 10, 10,
        10, 10, 10, 10, 10, 10, 10, 10, 10, 10}

DP := DVP ^ 2 / DRL
PMax = Max[DP]
CP := {}
For[h = 1, h ≤ 26, h++,
  TC = Extract[DTP, h] + 273.15;
  G = Extract[DGP, h];
  R = Extract[DRL, h];
  V = Extract[DVP, h];
  nT = nTr (TC / TR);
  Rs = Rsr (GR TR / TC G);
  Rsc = Rscr;
  Voc = Vocr - 1.09 10-1 (TC - TR) + Log[G / GR] / nTr3;
  Isc = Iscr (G / GR) + 3.18 10-3 (TC - TR);
  ans = y /. FindRoot[Isc - R y / Rsc - (Isc - Voc / Rsc) e(R y + Rs y - Voc) / nT - y == 0, {y, 1.5}];
  CP = Append[CP, ans ^ 2 10] ]

Show[ListLinePlot[{DP}, PlotStyle → Black],
  ListLinePlot[{CP}, PlotStyle → {Dashed, Thick, Orange}],
  Frame → True, AspectRatio → 1 / 1]
σ = √Mean[(CP - DP)2]
Correlation[CP, DP]
66.1499

```



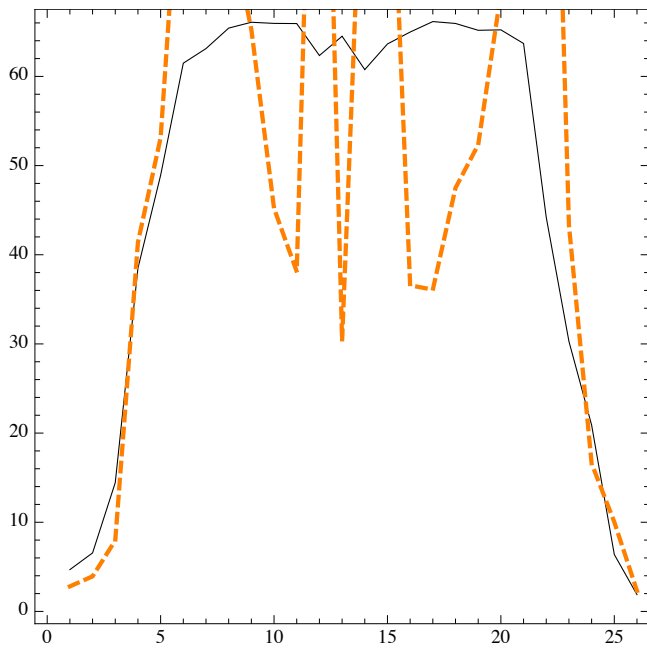
```

Vocr := 29.2
Iscr := 8.09
Vmpr := 23.6
Impr := 7.42
Rso :=  $\frac{29.2 - 28.279}{1.996}$ 
Rsho :=  $\frac{5.102}{8.09 - 8.011}$ 
DP := DVP^2 / DRL
CP1 := {}
For[h = 1, h ≤ 26, h++,
  T = Extract[DTP, h] + 273.15;
  G = Extract[DGP, h];
  R = Extract[DRL, h];
  V = Extract[DVP, h];
  Vt :=  $\frac{1.380658 \cdot 10^{-23} \cdot T}{1.6021773 \cdot 10^{-19}}$ ;

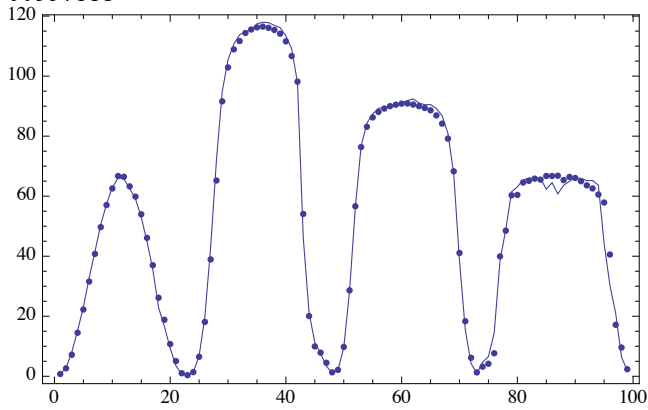
  m :=  $(Vmpr + Impr Rso - Vocr) / \left( Vt \left( \text{Log} \left[ Iscr - \frac{Vmpr}{Rsho} - Impr \right] - \text{Log} \left[ Iscr - \frac{Vocr}{Rsho} \right] + \frac{Impr}{Iscr - \frac{Vocr}{Rsho}} \right) \right)$ ;

  Voc = Vocr + m Vt Log  $\left[ \frac{G}{1000} \right] - 1.09 \cdot 10^{-1} (T - 298.15)$ ;
  Isc =  $\frac{Iscr G}{1000} + 3.18 \cdot 10^{-3} (T - 298.15)$ ;
  Rs =  $Rso - \frac{m Vt}{\left( Iscr - \frac{Vocr}{Rsho} \right)}$ ;
  IO :=  $\left( Iscr - \frac{Vocr}{Rsho} \right) e^{\left( \frac{-Voc}{m Vt} \right)}$ ;
  IL :=  $Isc \left( 1 + \frac{Rs}{Rsho} \right) + IO \left( e^{\frac{Isc Rs}{m Vt}} - 1 \right)$ ;
  ans = y /. FindRoot  $\left[ IL - IO \left( e^{\frac{V+Rs y}{m Vt}} - 1 \right) - \frac{V+Rs y}{Rsho} - y == 0, \{y, 2\} \right]$ ;
  CP1 = Append[CP1, ans^2 10] ]
σ =  $\sqrt{\text{Mean}[(CP1 - DP)^2]}$ 
Show[ListLinePlot[{DP}, PlotStyle → Black],
  ListLinePlot[{CP1}, PlotStyle → {Dashed, Thick, Orange}],
  Frame → True, AspectRatio → 1 / 1]
29.0047

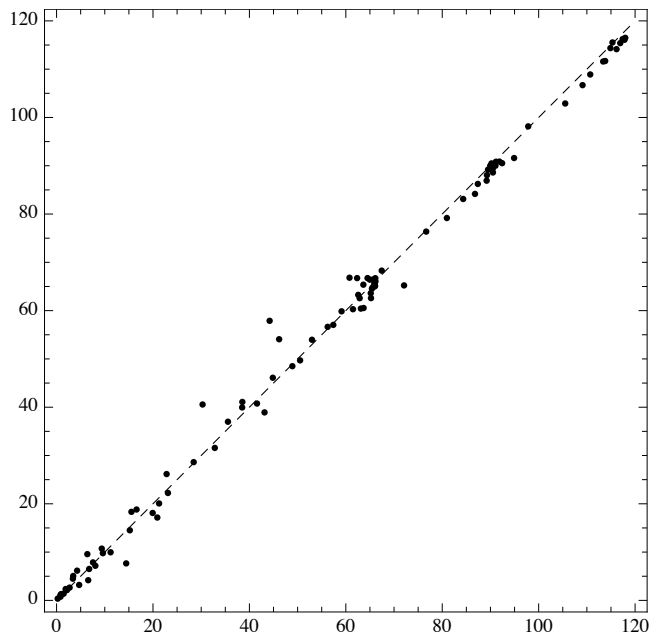
```



2.72471
0.997355



```
{ {0.821768, 0.763377}, {2.70379, 2.64563}, {8.04635, 7.16669},
{15.1936, 14.5117}, {23.1059, 22.2412}, {32.8212, 31.5725}, {41.5753, 40.7606},
{50.5156, 49.6982}, {57.4011, 57.0475}, {62.8712, 62.5736}, {66.1175, 66.7162},
{65.7267, 66.4774}, {62.5746, 63.2646}, {59.1188, 59.8571}, {52.9797, 53.9665},
{44.8584, 46.1021}, {35.5502, 36.9932}, {22.8236, 26.1602}, {16.5924, 18.8157},
{9.37264, 10.7178}, {3.44997, 5.05063}, {0.779846, 1.01827}, {0.231384, 0.360957},
{1.46164, 1.3878}, {6.75894, 6.50541}, {19.9327, 18.1004}, {43.1399, 38.9264},
{72.0807, 65.2236}, {94.9064, 91.5988}, {105.508, 102.894}, {110.7, 108.9},
{113.799, 111.69}, {114.881, 114.357}, {115.311, 115.533}, {117.425, 116.232},
{117.966, 116.49}, {117.802, 116.089}, {116.923, 115.394}, {116.156, 114.141},
{113.38, 111.589}, {109.104, 106.691}, {97.8353, 98.1531}, {46.1681, 54.0764},
{21.2635, 20.0713}, {11.2081, 9.95753}, {7.55575, 7.86447}, {3.38326, 4.49611},
{1.10132, 1.31288}, {2.1594, 2.13646}, {9.60579, 9.77413}, {28.4403, 28.6283},
{56.2332, 56.6437}, {76.6693, 76.3643}, {84.342, 83.1184}, {87.3763, 86.2373},
{89.2785, 88.0569}, {89.4961, 89.193}, {89.9563, 89.9989}, {90.2195, 90.4845},
{91.1348, 90.8272}, {91.8491, 90.8624}, {92.4204, 90.5344}, {91.0348, 90.0079},
{90.4727, 89.3904}, {90.5132, 88.6048}, {89.2086, 86.9118}, {86.7917, 84.1695},
{80.964, 79.1772}, {67.4477, 68.2841}, {38.5346, 41.089}, {15.529, 18.334},
{4.26039, 6.15585}, {0.911219, 1.28265}, {4.68712, 3.19853}, {6.56208, 4.17643},
{14.441, 7.65828}, {38.4941, 39.9508}, {48.9096, 48.4966}, {61.4836, 60.2933},
{63.1207, 60.421}, {65.4162, 64.5543}, {66.073, 65.1118}, {65.9458, 65.8521},
{65.9274, 65.5107}, {62.3418, 66.7348}, {64.5056, 66.7336}, {60.7634, 66.8131},
{63.638, 65.3719}, {64.9753, 66.4193}, {66.1499, 66.064}, {65.9385, 64.9908},
{65.1724, 63.6096}, {65.2209, 62.5867}, {63.6915, 60.5444}, {44.1956, 57.89},
{30.2886, 40.5612}, {20.8983, 17.152}, {6.38296, 9.57605}, {1.88416, 2.3491}
```



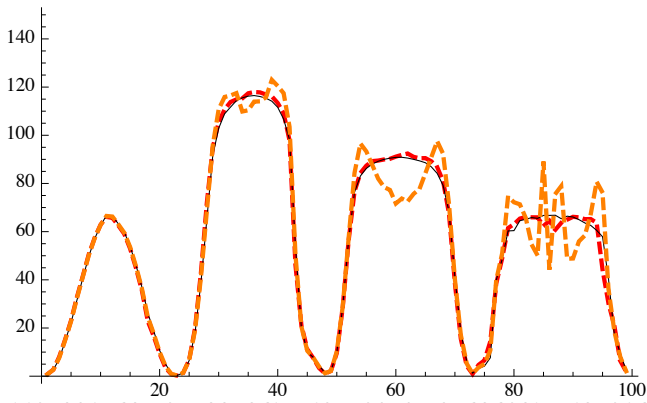
```

Vocr := 29.2
Iscr := 8.09
Vmpr := 23.6
Impr := 7.42
Rso :=  $\frac{29.2 - 28.279}{1.996}$ 
Rsho :=  $\frac{5.102}{8.09 - 8.011}$ 
DP := DVP^2 / DRL
CP1 := {}
For[h = 1, h ≤ 99, h++,
  T = Extract[DTP, h] + 273.15;
  G = Extract[DGP, h];
  R = Extract[DRL, h];
  V = Extract[DVP, h];
  Vt :=  $\frac{1.380658 \cdot 10^{-23} \cdot T}{1.6021773 \cdot 10^{-19}}$ ;

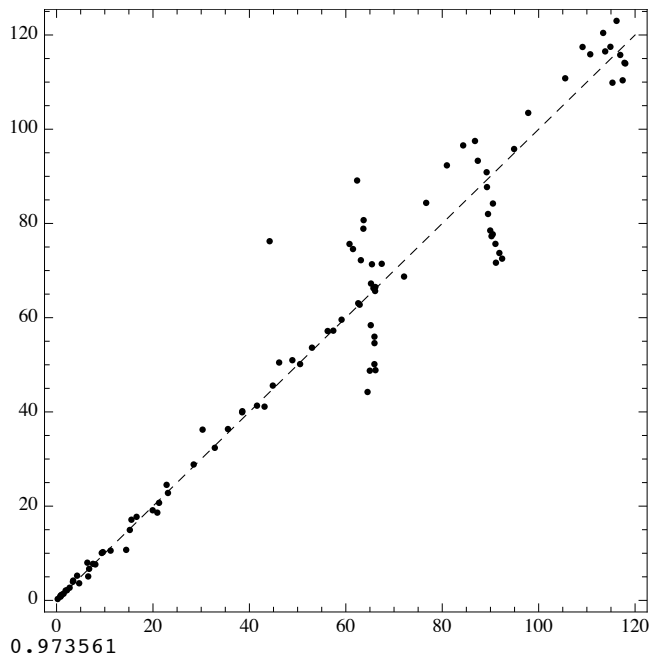
  m :=  $(Vmpr + Impr Rso - Vocr) / \left( Vt \left( \text{Log} \left[ Iscr - \frac{Vmpr}{Rsho} - Impr \right] - \text{Log} \left[ Iscr - \frac{Vocr}{Rsho} \right] + \frac{Impr}{Iscr - \frac{Vocr}{Rsho}} \right) \right)$ ;

  Voc = Vocr + m Vt Log  $\left[ \frac{G}{1000} \right] - 1.09 \cdot 10^{-1} (T - 298.15)$ ;
  Isc =  $\frac{Iscr G}{1000} + 3.18 \cdot 10^{-3} (T - 298.15)$ ;
  Rs =  $Rso - \frac{m Vt}{\left( Iscr - \frac{Voc}{Rsho} \right)}$ ;
  IO :=  $\left( Iscr - \frac{Voc}{Rsho} \right) e^{\left( \frac{-Voc}{m Vt} \right)}$ ;
  IL :=  $Isc \left( 1 + \frac{Rs}{Rsho} \right) + IO \left( e^{\frac{Isc Rs}{m Vt}} - 1 \right)$ ;
  ans = y /. FindRoot  $\left[ IL - IO \left( e^{\frac{V+Rs y}{m Vt}} - 1 \right) - \frac{V+Rs y}{Rsho} - y = 0, \{y, 1.5\} \right]$ ;
  CP1 = Append[CP1, ans V]
]
σ =  $\sqrt{\text{Mean}[(CP1 - DP)^2]}$ 
Show[ListLinePlot[{DP}, PlotStyle → {Dashed, Thick, Red}],
  ListLinePlot[{CP}, PlotStyle → Black],
  ListLinePlot[{CP1}, PlotStyle → {Dashed, Thick, Orange}],
  PlotRange → {0, 150}]
m = Transpose[ArrayFlatten[{DP, CP1}]]
Show[ListPlot[m, PlotStyle → {Dashed, Thick, Black}],
  Plot[x = 0, {x, 0, 120}, PlotStyle → {Dashed, Black}], Frame → True, AspectRatio → 1 / 1]
Correlation[DP, CP1]
8.51485

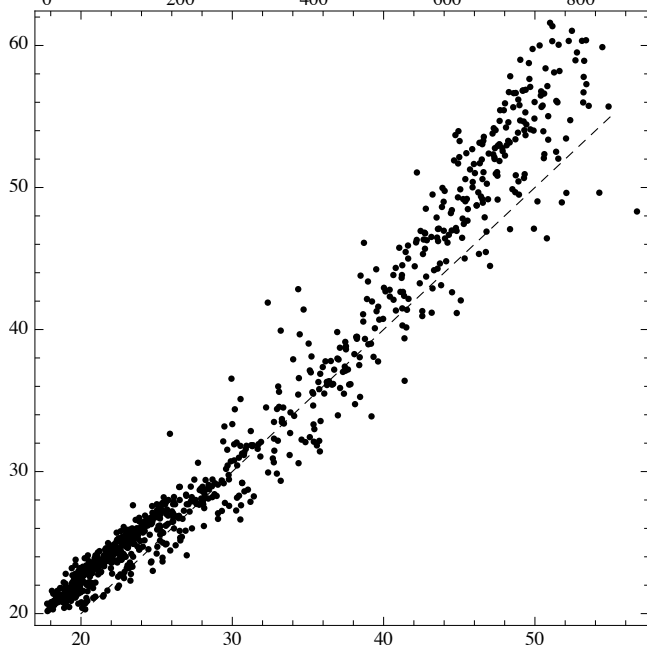
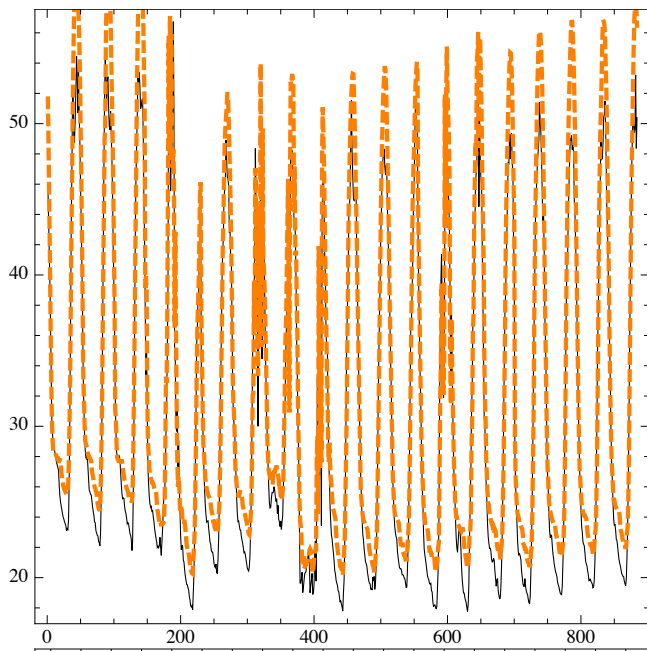
```

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{ {0.821768, 0.788786}, {2.70379, 2.68608}, {8.04635, 7.63095}, {15.1936, 14.9441},
{23.1059, 22.7953}, {32.8212, 32.381}, {41.5753, 41.3249}, {50.5156, 50.1503},
{57.4011, 57.2404}, {62.8712, 62.7559}, {66.1175, 66.5071}, {65.7267, 66.2612},
{62.5746, 63.0638}, {59.1188, 59.5735}, {52.9797, 53.6343}, {44.8584, 45.587},
{35.5502, 36.3614}, {22.8236, 24.5203}, {16.5924, 17.7313}, {9.37264, 10.0623},
{3.44997, 4.2018}, {0.779846, 0.896874}, {0.231384, 0.290317}, {1.46164, 1.42345},
{6.75894, 6.69441}, {19.9327, 19.1231}, {43.1399, 41.1165}, {72.0807, 68.725},
{94.9064, 95.7997}, {105.508, 110.808}, {110.7, 115.901}, {113.799, 116.516},
{114.881, 117.487}, {115.311, 109.871}, {117.425, 110.379}, {117.966, 113.951},
{117.802, 114.092}, {116.923, 115.763}, {116.156, 122.995}, {113.38, 120.436},
{109.104, 117.454}, {97.8353, 103.465}, {46.1681, 50.4825}, {21.2635, 20.6999},
{11.2081, 10.5557}, {7.55575, 7.75099}, {3.38326, 3.96628}, {1.10132, 1.21543},
{2.1594, 2.15636}, {9.60579, 10.2399}, {28.4403, 28.8417}, {56.2332, 57.167},
{76.6693, 84.3675}, {84.342, 96.5636}, {87.3763, 93.2999}, {89.2785, 87.7195},
{89.4961, 82.0099}, {89.9563, 78.5}, {90.2195, 77.2952}, {91.1348, 71.6661}, {91.8491, 73.7289},
{92.4204, 72.5299}, {91.0348, 75.6655}, {90.4727, 77.7019}, {90.5132, 84.2293},
{89.2086, 90.8697}, {86.7917, 97.5021}, {80.964, 92.328}, {67.4477, 71.4366},
{38.5346, 40.1513}, {15.529, 17.1221}, {4.26039, 5.24038}, {0.911219, 1.07715},
{4.68712, 3.62905}, {6.56208, 5.08119}, {14.441, 10.7219}, {38.4941, 39.9189},
{48.9096, 50.973}, {61.4836, 74.5673}, {63.1207, 72.1984}, {65.4162, 71.3397},
{66.073, 65.6633}, {65.9458, 54.596}, {65.9274, 50.134}, {62.3418, 89.1121}, {64.5056, 44.2298},
{60.7634, 75.6414}, {63.638, 78.886}, {64.9753, 48.7467}, {66.1499, 48.8584}, {65.9385, 55.965},
{65.1724, 58.4041}, {65.2209, 67.244}, {63.6915, 80.7019}, {44.1956, 76.2291},
{30.2886, 36.2371}, {20.8983, 18.622}, {6.38296, 7.99947}, {1.88416, 2.08522}
```



Correlazione fra Ta e Tc**A := 1.29 × 0.99****TN := 47****VmN := 20.9****ImN := 5.99****eta := 0.16****TA = Flatten[Drop[Take[Extract[Import["Desktop/Correlazione Ta,Tc/due parametri/Kyocera/1Data copia.xls"], 1], All, {1}], 1]]****TCM = Flatten[Drop[Take[Extract[Import["Desktop/Correlazione Ta,Tc/due parametri/Kyocera/1Data copia.xls"], 1], All, {2}], 1]]****G = Flatten[Drop[Take[Extract[Import["Desktop/Correlazione Ta,Tc/due parametri/Kyocera/1Data copia.xls"], 1], All, {3}], 1]]****Y = Flatten[Drop[Take[Extract[Import["Desktop/Correlazione Ta,Tc/due parametri/Kyocera/1Data copia.xls"], 1], All, {4}], 1]]****R = Flatten[Drop[Take[Extract[Import["Desktop/Correlazione Ta,Tc/due parametri/Kyocera/1Data copia.xls"], 1], All, {5}], 1]]****Data = Flatten[Drop[Take[Extract[Import["Desktop/Correlazione Ta,Tc/due parametri/Kyocera/1Data copia.xls"], 1], All, {1, 2}], 1]]****TC = TA + $\frac{TN-20}{800}$ G - $\frac{R Y^2}{VmN ImN}$**
 $0.25 (TN-20)$ **ans = Transpose[ArrayFlatten[{TCM, TC}]]****Show[ListLinePlot[TCM, PlotStyle → Black],****ListLinePlot[TC, PlotStyle → {Dashed, Thick, Orange}], Frame → True, AspectRatio → 1 / 1]****Show[ListPlot[ans, PlotStyle → Black], Plot[x, {x, 20, 55}, PlotStyle → {Dashed, Black}],****Frame → True, AspectRatio → 1 / 1]****ERR = $\sqrt{\text{Mean}[(TCM - TC)^2]}$** **Correlation[TCM, TC]****TC1 = TA + $\frac{(0.9-0.16)(TN-20)}{0.9 \times 800}$ G****ans1 = Transpose[ArrayFlatten[{TCM, TC1}]]****Show[ListPlot[ans1, PlotStyle → Black],****Plot[x, {x, 10, 55}, PlotStyle → {Dashed, Black}], Frame → True, AspectRatio → 1 / 1]****ERR = $\sqrt{\text{Mean}[(TCM - TC1)^2]}$** **Correlation[TCM, TC1]**



3.15168
0.980178

