LV51140T — 1-Cell Lithium-Ion Battery Protection IC

Overview

The LV51140T is protection IC for rechargeable Li-ion battery by high withstand voltage CMOS process. The LV51140T protect single-cell Li-ion battery from over-charge, over-discharge, charge over-current and discharge over-current.

Features

- High accuracy detection voltage
  - Over-charge detection: ±25mV
  - Over-charge hysteresis: ±25mV
  - Over-discharge detection: ±25%
  - Charge over-current detection: ±0.3V
  - Discharge over-current detection: ±20mV

- Delay time (internal adjustment)

- Low current consumption
  - Operation: Typ. 3.0µA
  - Over-discharge condition: Max. 0.1µA

- 0V cell battery charging function

Specifications

Absolute Maximum Ratings at Ta = 25°C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Ratings</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>VDD</td>
<td>0.3 to VSS+7</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Input voltage of VM</td>
<td>VM</td>
<td>VDD-28 to VDD+0.3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Output voltage of CO</td>
<td>VCO</td>
<td>VSS-0.3 to VDD+0.3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Output voltage of DO</td>
<td>VDO</td>
<td>VSS-0.3 to VDD+0.3</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Power dissipation</td>
<td>PD</td>
<td></td>
<td>350 mW</td>
<td></td>
</tr>
<tr>
<td>Operating temperature</td>
<td>Topr</td>
<td></td>
<td>-40 to +85°C</td>
<td></td>
</tr>
<tr>
<td>Storage temperature</td>
<td>Tstg</td>
<td></td>
<td>-55 to +125°C</td>
<td></td>
</tr>
</tbody>
</table>

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### Electrical Characteristics at ToPr = 25°C, unless otherwise specified

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Test circuit</th>
<th>Ratings</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over-charge detection voltage</td>
<td>VC</td>
<td></td>
<td>1</td>
<td>4.225</td>
<td>4.250</td>
</tr>
<tr>
<td>Over-charge hysteresis voltage</td>
<td>VHc</td>
<td></td>
<td>1</td>
<td>0.175</td>
<td>0.2</td>
</tr>
<tr>
<td>Over-discharge detection voltage</td>
<td>Vdc</td>
<td></td>
<td>1</td>
<td>2.438</td>
<td>2.500</td>
</tr>
<tr>
<td>Over-discharge reset voltage</td>
<td>VRdc</td>
<td></td>
<td>1</td>
<td>2.633</td>
<td>2.700</td>
</tr>
<tr>
<td>Charge over-current detection voltage</td>
<td>Vlc</td>
<td></td>
<td>2</td>
<td>-1.000</td>
<td>-0.700</td>
</tr>
<tr>
<td>Discharge over-current detection voltage</td>
<td>VIdc</td>
<td></td>
<td>2</td>
<td>0.180</td>
<td>0.200</td>
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<tr>
<td>Load short-circuiting detection voltage</td>
<td>Vshort</td>
<td>Based on VDD, VDD = 3.5V</td>
<td>2</td>
<td>-1.7</td>
<td>-1.3</td>
</tr>
</tbody>
</table>

#### Input voltage

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Test circuit</th>
<th>Ratings</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage between VDD and VSS</td>
<td>VDD</td>
<td>Internal circuit operating voltage</td>
<td>-</td>
<td>1.8</td>
<td>7.0</td>
</tr>
<tr>
<td>0V battery charge starting charger voltage</td>
<td>Vcha</td>
<td>Acceptable</td>
<td>3</td>
<td>0.9</td>
<td>1.4</td>
</tr>
</tbody>
</table>

#### Current consumption

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Test circuit</th>
<th>Ratings</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current consumption on operation</td>
<td>Iopr</td>
<td>VDD = 3.5V, VM = 0V</td>
<td>4</td>
<td>3.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Current consumption on shutdown</td>
<td>Isdn</td>
<td>VDD = VM = 1.8V</td>
<td>4</td>
<td>0.1</td>
<td>μA</td>
</tr>
</tbody>
</table>

#### Output resistance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Test circuit</th>
<th>Ratings</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO : Pch ON resistance</td>
<td>Rcop</td>
<td>CO = 3.0V, VDD = 3.5V, VM = 0V</td>
<td>5</td>
<td>1.5</td>
<td>3.0</td>
</tr>
<tr>
<td>CO : Nch ON resistance</td>
<td>Rcon</td>
<td>CO = 0.5V, VDD = 4.6V, VM = 0V</td>
<td>5</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>DO : Pch ON resistance</td>
<td>Rdop</td>
<td>DO = 3.0V, VDD = 3.5V, VM = 0V</td>
<td>5</td>
<td>1.7</td>
<td>3.5</td>
</tr>
<tr>
<td>DO : Nch ON resistance</td>
<td>Rdon</td>
<td>DO = 0.5V, VDD = VM = 1.8V</td>
<td>5</td>
<td>1.7</td>
<td>3.5</td>
</tr>
<tr>
<td>Discharge over-current release resistance</td>
<td>Rdwn</td>
<td>VDD = 3.5V, VM = 1.0V</td>
<td>5</td>
<td>15.0</td>
<td>30.0</td>
</tr>
</tbody>
</table>

#### Detection delay time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Test circuit</th>
<th>Ratings</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over-charge detection delay time</td>
<td>tc</td>
<td>VDD = VC-0.2V→VC+0.2V, VM = 0V</td>
<td>6</td>
<td>0.70</td>
<td>1.0</td>
</tr>
<tr>
<td>Over-discharge detection delay time</td>
<td>tdc</td>
<td>VDD = Vdc+0.2V→Vdc-0.2V, VM = 0V</td>
<td>6</td>
<td>21.7</td>
<td>31.0</td>
</tr>
<tr>
<td>Charge over-current detection delay time</td>
<td>tic</td>
<td>VDD = 3.5V, VM = 0V→+1.0V</td>
<td>6</td>
<td>5.6</td>
<td>8.0</td>
</tr>
<tr>
<td>Discharge over-current detection delay time</td>
<td>tIdc</td>
<td>VDD = 3.5V, VM = 0V→+1.0V</td>
<td>6</td>
<td>5.6</td>
<td>8.0</td>
</tr>
<tr>
<td>Load short-circuiting detection delay time</td>
<td>tshort</td>
<td>VDD = 3.5V, VM = 0V→3.5V</td>
<td>6</td>
<td>190</td>
<td>370</td>
</tr>
</tbody>
</table>

#### Release delay time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Conditions</th>
<th>Test circuit</th>
<th>Ratings</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release delay time 1</td>
<td>tre1</td>
<td>Over-discharge release</td>
<td>6</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Charge over-current release (*1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge over-current release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load short-circuiting release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Release delay time 2</td>
<td>tre2</td>
<td>Over-charge release</td>
<td>6</td>
<td>8.0</td>
<td>16.0</td>
</tr>
</tbody>
</table>

Note: *1 Upon connecting to charger upon over-discharge, the delay time after recovery from over-discharge.
LV51140T

Package Dimensions
unit : mm (typ)
3356

Pin Assignment

Pin Function

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Pin Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DO</td>
<td>FET gate connection for discharge control (CMOS output)</td>
</tr>
<tr>
<td>2</td>
<td>VM</td>
<td>Voltage monitoring for charger negative</td>
</tr>
<tr>
<td>3</td>
<td>CO</td>
<td>FET gate connection for charge control (CMOS output)</td>
</tr>
<tr>
<td>4</td>
<td>NC</td>
<td>N/C</td>
</tr>
<tr>
<td>5</td>
<td>VDD</td>
<td>Positive power input</td>
</tr>
<tr>
<td>6</td>
<td>VSS</td>
<td>Negative power input</td>
</tr>
</tbody>
</table>
Measurement Conditions

- **Over-charge detection voltage, Over-charge hysteresis voltage --- [Circuit 1]**
  Set $V1 = 3.5V$ and $V2 = 0V$. Over-charge detection voltage $VC$ is $V1$ at which $VCO$ goes "Low" from "High" when $V1$ is gradually increased from 3.5V. Then IC is released from the over-charge state and $VCO$ goes "High" from "Low" at the voltage "Measured $VC-VHc$" when $V1$ is gradually decreased.
  If $V2$ is set to the greater value than discharge over-current detection voltage $VIdc$ in the over-charge state, $VHc$ is canceled and then IC is released from the over-charge state at $VC$.

- **Over-discharge detection voltage --- [Circuit 1]**
  Set $V1 = 3.5V$ and $V2 = 0V$. Over-discharge detection voltage $Vdc$ is $V1$ at which $VDO$ goes "Low" from "High" when $V1$ is gradually decreased from 3.5V. Next, set $V2$ under to charge over-current detection voltage $VIc$. Then IC is released from the over-discharge state at $Vdc$ and $VDO$ goes "High" from "Low".

- **Charge over-current detection voltage --- [Circuit 2]**
  Set $V1 = 3.5V$ and $V2 = 0V$. Charge over-current detection voltage $VIc$ is $V2$ at which $VCO$ goes "Low" from "High" when $V2$ is gradually decreased from 0V.

- **Discharge over-current detection voltage --- [Circuit 2]**
  Set $V1 = 3.5V$ and $V2 = 0V$. Discharge over-current detection voltage $VIdc$ is $V2$ at which $VDO$ goes "Low" from "High" when $V2$ is gradually increased from 0V.

- **Load short-circuiting detection voltage --- [Circuit 2]**
  Set $V1 = 3.5V$ and $V2 = 0V$. Load short-circuiting detection voltage $Vshort$ is $V2$ at which $VDO$ goes "Low" from "High" within a time between the minimum and the maximum value of load short-circuiting detection delay time $tshort$, when $V2$ is increased rapidly within $10\mu s$.

- **0V battery charge starting charger voltage --- [Circuit 3]**
  Set $V1 = V2 = 0V$ and decrease $V2$ gradually. 0V battery charge starting charger voltage $Vcha$ is $V2$ when $VCO$ goes "High" ($V1-0.1V$ or higher).

Continued on next page.
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- **Current consumption on operation and shutdown** --- [Circuit 4]
  Set V1 = 3.5V and V2 = 0V on normal condition. IDD shows current consumption on operation Iopr.
  Set V1 = V2 = 1.8V on over-discharge condition. IDD shows current consumption on shutdown Isdn.

- **Co : Pch ON resistance, Co : Nch ON resistance** --- [Circuit 5]
  Set V1 = 3.5V, V2 = 0V and V3 = 3.0V. (V1-V3)/|ICo| is Pch ON resistance Rcop.
  Set V1 = 4.6V, V2 = 0V and V3 = 0.5V. V3/|ICo| is Nch ON resistance Rcon.

- **Do : Pch ON resistance, Do : Nch ON resistance** --- [Circuit 5]
  Set V1 = 3.5V, V2 = 0V and V4 = 3.0V. (V1-V4)/|IDo| is Pch ON resistance Rdop.
  Set V1 = V2 = 1.8V and V4 = 0.5V. V4/|IDo| is Nch ON resistance Rdon.

- **Discharge over-current release resistance** --- [Circuit 5]
  Set V1 = 3.5V, V2 = 0V at first. And then, set V2 = 1.0V. V2/|VM| is discharge over-current release resistance Rdwn.

- **Over-charge detection delay time, Release delay time 2** --- [Circuit 6]
  Set V2 = 0V. Increase V1 from the voltage VC-0.2V to VC+0.2V rapidly within 10µs. Over-charge detection delay time tc is the time needed for VCO to go "Low" just after the change of V1.
  Next, set V2 = 1V and decrease V1 from VC+0.2V to VC-0.2V rapidly within 10µs. Over-charge release delay time trel 2 is the time needed for VCO to go "High" just after the change of V1.

- **Over-discharge detection delay time, Release delay time 1** --- [Circuit 6]
  Set V2 = 0V. Decrease V1 from the voltage Vdc+0.2V to Vdc-0.2V rapidly within 10µs. Over-discharge detection delay time tdc is the time needed for VDO to go "Low" just after the change of V1.
  Next, set V2 = -1V and increase V1 from Vdc-0.2V to Vdc+0.2V rapidly within 10µs. Release delay time 1 trel1 in case of over-discharge is the time needed for VDO to go "High" just after the change of V1.

- **Charge over-current detection delay time, Release delay time 1** --- [Circuit 6]
  Set V1 = 3.5V and V2 = 0V. Decrease V2 from 0V to -1V rapidly within 10µs. Charge over-current delay time tic is the time needed for VCO to go "Low" just after the change of V2.
  Next, increase V2 from -1V to 0V rapidly within 10µs. Release delay time 1 trel1 in case of charge over-current is the time needed for VCO to go "High" just after the change of V2.

- **Discharge over-current detection delay time, Release delay time 1** --- [Circuit 6]
  Set V1 = 3.5V and V2 = 0V. Increase V2 from 0V to 1V rapidly within 10µs. Discharge over-current delay time tdoc is the time needed for VDO to go "Low" just after the change of V2.
  Next, decrease V2 from 1V to 0V rapidly within 10µs. Release delay time 1 trel1 in case of discharge over-current is the time needed for VDO to go "High" just after the change of V2.

- **Load short-circuiting detection delay time, Release delay time 1** --- [Circuit 6]
  Set V1 = 3.5V and V2 = 0V. Increase V2 from 0V to 3.5V rapidly within 10µs. Load short-circuiting detection delay time tshort is the time needed for VDO to go "Low" just after the change of V2.
  Next, decrease V2 from 3.5V to 0V rapidly within 10µs. Release delay time 1 trel1 in case of load short-circuiting is the time needed for VDO to go "High" just after the change of V2.
Measurement Circuits

- Circuit 1

- Circuit 2

- Circuit 3

- Circuit 4

- Circuit 5

- Circuit 6

TM = Time Measurement
Application Circuit Example

![Application Circuit Example Diagram]

**External Components**

<table>
<thead>
<tr>
<th>Items</th>
<th>Symbol</th>
<th>Recommended value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistor 1</td>
<td>R1</td>
<td>330Ω</td>
</tr>
<tr>
<td>Capacitor 1</td>
<td>C1, 2</td>
<td>0.1µF</td>
</tr>
<tr>
<td>Resistor 2</td>
<td>R2</td>
<td>3.9kΩ</td>
</tr>
</tbody>
</table>

- The supply voltage (VDD) to this IC is stabilized by R1 and C1. Moreover, R1 and R2 act as the current restriction resistances at the time of reverse-connecting a charger, or at the time of connecting a charger which outputs the voltage exceeding the absolute maximum rating of this IC. Be sure to connect these components.

- If the value of R1 is too large, the over-charge detection voltage will become high due to the current consumption of this IC. 330Ω is recommended.

- If the value of C1 is too small, this IC may be in a shutdown state at the time of the discharge over-current or the load short-circuiting. 0.1µF is recommended.

- Use the value within the limits shown in the table about the value of R2. In order to reduce the current at the time of reverse-connecting a charger, we recommend to choose R1 and R2 so that the sum total of resistance values is more than 4kΩ. The recommended value of R2 is 3.9kΩ.

Note 1 : The connection diagram and each value of external components shown above are just recommendation. Including a battery and FETs, determine the circuit after sufficient evaluation about your actual application.

Note 2 : The IC is susceptible to static electricity and some pins are easily damaged by it. Handle the IC carefully.
Description of Operation

• Normal condition
This IC monitors the battery voltage (\(V_{DD}\)) and the voltage of \(V_M\) terminal, and controls charge and discharge.
If the battery voltage (\(V_{DD}\)) is in the range from the over-discharge detection voltage (\(V_{dc}\)) to the over-charge detection voltage (\(V_C\)) and the \(V_M\) terminal voltage is in the range from the charge over-current detection voltage (\(V_{Ic}\)) to the discharge over-current detection voltage (\(V_{Idc}\)), this IC turns on both the charge and discharge control FETs. This state is called the normal condition, and charge and discharge are possible together.

• Discharge over-current detection, Load short-circuiting detection
When the discharge current becomes equal to or higher than the specified value under the normal condition, and if the \(V_M\) terminal voltage is in the range from the discharge over-current detection voltage (\(V_{Idc}\)) to the short-circuiting detection voltage (\(V_{short}\)) and that state is maintained during more than the discharge over-current detection delay time (\(t_{idc}\)), this IC turns off the discharge control FET to stop discharge. This state is called the discharge over-current condition.
At that time, if the \(V_M\) terminal voltage is equal to or higher than \(V_{short}\) and that state is maintained during more than the load short-circuiting detection delay time (\(t_{short}\)), this IC turns off the discharge control FET to stop discharge. This state is called the load short-circuiting detection condition.
While load is connected, in both conditions, the \(V_M\) terminal voltage equals to \(V_{DD}\) potential due to the load, but it falls by the discharge over-current release resistance (\(R_{dwn}\)) when the load is removed and the resistance between (+) and (-) terminals of battery pack (refer to “Application Circuit Example”) becomes larger than the value which enables the automatic return.
Then the \(V_M\) terminal voltage becomes less than \(V_{Idc}\), and if that state is maintained during more than the release delay time 1 (\(t_{rel1}\)), this IC returns to normal condition.

Note : The resistance value between (+) and (-) terminals of battery pack for automatic return changes with battery voltage (\(V_{DD}\) or \(V_{Idc}\). The standard is expressed with the following equation.
\[\text{Resistance value for automatic return} = R_{dwn} \times \left(\frac{V_{DD}}{V_{Idc}} - 1\right)\]

• Charge over-current detection
When the charge current becomes equal to or higher than the specified value under the normal condition, if the \(V_M\) terminal voltage becomes less than the charge over-current detection voltage (\(V_{Ic}\)) and that state is maintained during more than the charge over-current detection delay time (\(t_{ic}\)), this IC turns off the charge control FET to stop charge. This state is called the charge over-current detection condition.
Then the \(V_M\) terminal voltage becomes equal to or higher than \(V_{Ic}\) and that state is maintained during more than the release delay time 1 (\(t_{rel1}\)) when the charger is removed and the load is connected, this IC returns to the normal condition.

Note : If the \(V_M\) terminal voltage becomes equal to or less than \(V_{SS}-7V\) (typical), the charge over-current detection delay time (\(t_{ic}\)) changes as below.

<table>
<thead>
<tr>
<th>Model</th>
<th>.dumps_model</th>
<th>8ms (not changed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8ms model</td>
<td>8ms model</td>
<td>7ms (typical)</td>
</tr>
<tr>
<td>125ms model</td>
<td>56ms (typical)</td>
<td></td>
</tr>
</tbody>
</table>

• Over-charge detection
When the battery voltage (\(V_{DD}\)) under the normal condition becomes equal to or higher than the over-charge detection voltage (\(V_C\)) and that state is maintained during more than the over-charge detection delay time (\(t_{c}\)), this IC turns off the charge control FET and stops charge. This state is called the over-charge detection condition. Release from the over-charge detection condition includes following three cases.
(1) When \(V_{DD}\) falls to \(V_{c}-V_{Hc}\) without load and that state is maintained during more than the delay time 2 (\(t_{rel2}\)), this IC turns on the charge control FET and returns to the normal condition.
* \(V_{Hc}\) : Over-charge hysteresis voltage
(2) When the load is installed and discharge starts, the discharge current flows through the internal parasitic diode of the charge control FET. Then the \(V_M\) terminal voltage rises to only the \(V_f\) voltage of the internal parasitic diode from \(V_{SS}\) potential. At this time, if the \(V_M\) terminal voltage is higher than the discharge over-current detection voltage (\(V_{Idc}\) and \(V_{DD}\) is equal to or less than \(V_C\), this IC returns to the normal condition when this state continues more than the delay time 2 (\(t_{rel2}\)).
(3) In case (2), if the \(V_M\) terminal voltage is higher than the discharge over-current detection voltage (\(V_{Idc}\) and \(V_{DD}\) is equal to or higher than \(V_C\), battery is discharged until \(V_{DD}\) becomes less than \(V_C\), and then this IC returns to the normal condition when this state continues more than the delay time 2 (\(t_{rel2}\)).
• Over-discharge detection
When the battery voltage (V_{DD}) under the normal condition becomes equal to or less than the over-discharge detection voltage (V_{dc}) and that state continues for more than the over-discharge detection time (t_{dc}), this IC turns off the discharge control FET and stops discharging. This state is called the over-discharge detection condition. Recovery from the over-discharge detection condition is achieved only by connecting the charger.

• Return from over-discharge
When the charger is connected and charging starts, the charge current flows through the internal parasitic diode of the discharge control FET. If the V_{M} terminal voltage is higher than the charge over-current detection voltage (V_{Ic}), the IC returns to the normal condition when V_{DD} becomes equal to or higher than V_{Rdc} and this state continues more than the delay time1 (t_{rel1}).
If the V_{M} terminal voltage is lower than the charge over-current detection voltage (V_{Ic}), same as the above-mentioned case, the IC returns to the normal condition when V_{DD} becomes equal to or higher than V_{dc} and this state continues more than the delay time1 (t_{rel1}).

This IC stops all internal circuits (Shutdown condition) after detecting the over-discharge and reduces current consumption. (Max 0.1\mu A, at V_{DD} = 1.8V)

• 0V battery charge function
If the voltage of charger (the voltage between V_{DD} and V_{M}) is larger than the 0V battery charge starting charger voltage (V_{cha}), 0V battery charge becomes possible when CO terminal outputs V_{DD} terminal potential and turns on the charge control FET.
Timing Chart
• Discharge over-current detection, Load short-circuiting detection, Charge over-current detection

VC: Over-charge detection voltage
tic: Charge over-current detection delay time
Vdc: Over-discharge detection voltage
tidc: Discharge over-current detection delay time
VIlc: Charge over-current detection voltage
tshort: Load short-circuiting detection delay time
VIdc: Discharge over-current detection voltage
trel1: Release delay time 1
Vshort: Load short-circuiting detection voltage
• Over-charge detection

VC : Over-charge detection voltage
Vdc : Over-discharge detection voltage
VHc : Over-charge hysteresis voltage
Vidc : Discharge over-current detection voltage

**Diagram:**
- **VC** : Over-charge detection voltage
- **Vdc** : Over-discharge detection voltage
- **VHc** : Over-charge hysteresis voltage
- **Vidc** : Discharge over-current detection voltage

**Definitions:**
- **tc** : Over-charge detection delay time
- **tre2** : Release delay time 2

Connection States:
- Charger connected
- Load connected

**Diagram Notes:**
- VC-VHc: Over-charge detection voltage
- VDC, VSS, VM: Voltage levels
- TC, tre2: Time intervals

Diagram shows voltage levels and time intervals under different connection states.
- Over-discharge detection

VC : Over-charge detection voltage  
Vdc : Over-discharge detection voltage  
VRdc : Return from over-discharge voltage  
Vic : Charge over-current detection voltage  
Vidc : Discharge over-current detection voltage  
tdc : Over-discharge detection delay time  
trel1 : Release delay time 1
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