This manual has copyrights by Operation Technology, Inc. All rights reserved. Under the copyright laws, this manual may not be copied, in whole or in part, without the written consent of Operation Technology, Inc. The Licensee may copy portions of this documentation only for the exclusive use of Licensee. Any reproduction shall include the copyright notice. This exception does not allow copies to be made for other persons or entities, whether or not sold. Under this law, copying includes translating into another language.

Certain names and/or logos used in this document may constitute trademarks, service marks, or trade names of Operation Technology, Inc. or other entities.

- AutoCad is a registered trademark of Autodesk.
- Oracle is a registered trademark of Oracle Corporation.
- PowerPlot is a registered trademark of Jackson & Associates.
- Crystal Reports is a registered trademark of Seagate Software.
- MATLAB and Simulink are registered trademarks of MathWorks.
- Screen shot(s) reprinted by permission from Microsoft Corporation.

Operation Technology, Inc. believes that the information contained herein is accurate as of its publication date, and such information is subject to change without notice. This information is provided “as is” without warranty of any kind, either expressed or implied, including but not limited to the implied warranties of merchantability, fitness for a particular purpose, or non-infringement. Operation Technology, Inc. assumes no responsibility for errors or omissions in this publication or any other documents referenced in this publication.
Chapter 25

DC Load Flow Analysis

The DC power system is an integral part of the whole electric power system, providing power to control circuits and backup power during emergency conditions. It includes DC power sources, their distribution systems, and vital supporting systems that supply power to critical equipment.

In the past, due to lack of analytical tools, DC power system design and validation studies have been mainly done by hand-calculations, limited to simplified calculations on simple system configurations. Such simplified hand-calculations cannot meet today’s requirement for DC system analysis, especially for the nuclear power industry. ETAP DC program is an ideal tool for you to perform DC system studies. It provides a diversity of DC components and calculations required for conducting DC power system design and validation studies. It can handle any system configuration at ease, including radial system; loop system and AC-DC interconnected system.

A variety of DC components and AC-DC power conversion components are available for you to model the DC power system, including:

- DC battery
- DC bus and node
- DC cable
- DC machine, static load, lumped load, and elementary diagram (ED) load
- DC protective devices, such as circuit breaker, fuse, switch, and contact
- DC composite network and DC composite motor
- DC-DC converter
- AC-DC power conversion components, such as charger/rectifier, inverter, and UPS

DC load flow analysis is an essential study for DC system design and operating condition assessment. The PowerStation load flow program calculates bus voltage profile and branch power flows for a user-specified loading category. It validates the calculated operating conditions against element operating limits, such as bus maximum/minimum operating voltage, branch allowable current, and source maximum output, etc. In case any abnormal operating condition occurs in the system, PowerStation flags the user in the one-line diagram by showing the element in an outstanding color.
DC Load Flow Analysis

In order to simulate correctly various operating modes for AC-DC interface components in actual operations, PowerStation provides different models to represent them in load flow studies. It automatically selects the one that is suitable for the actual operating condition. For example, a charger may be operating in constant voltage, constant current, or non-effective modes, depending on its terminal bus voltage and loading conditions.

The calculation results are reported in a Crystal Reports format as well as in the one-line diagram display. The Crystal Reports format provides detailed information about the study, including all the input data used in the calculation, system voltage profile, branch power flows, and overloading validation results, etc. The one-line diagram display provides you with a direct visual representation of system operating conditions.
25.1 Study Toolbar

The DC Load Flow Study Toolbar will appear on the screen when you are in DC Load Flow Study mode.

- Run DC Load Flow Studies
- DC Load Flow Display Options
- DC Load Flow Report Manager
- Halt Current Calculation
- Get Online Data
- Get Archived Data

**Run DC Load Flow Studies**
Click on this button to run a DC load flow calculation using the parameters currently selected in the DC Load Flow Study Case Editor. Note that PowerStation will give you an error message list indicating missing information if your system is not set up properly.

**DC Load Flow Display Options**
Click on this button to customize the information and results annotations displayed on the one-line diagram in DC Load Flow mode.

**DC Load Flow Report Manager**
Click on this button to open the DC Load Flow Report Manager. Here, you can select the Crystal Reports format for your output reports. A detailed explanation of the DC Load Flow Report Manager is in the Output Reports section.

**Halt Current Calculation**
Click on the Stop Sign button to halt the current calculation.

**Get On-Line Data**
If the ETAP key installed on your computer has the on-line feature, you can copy the on-line data from the online presentation to the current presentation.

**Get Archived Data**
If the ETAP key installed on your computer has the on-line feature, you can copy the archived data to the current presentation.
25.2 Study Case Editor

The DC Load Flow Study Case Editor allows you to specify variables related to DC load flow calculations and output reports.

**Study Case ID**

Enter a unique alphanumeric ID with a maximum of 12 characters. PowerStation automatically assigns a unique ID, which consists of the letters DCLF plus an integer, starting with the number 1 and increases as the number of study cases increases.

**Solution Parameters (Newton-Raphson)**

The PowerStation DC load flow study uses the Newton-Raphson method for calculation.

**Maximum Iteration**

Enter the maximum number for iterations. If the solution has not converged before the specified number of iterations, a message will show up to flag the user.

**Precision**

Enter the value for the solution precision to be used to check for convergence. This value determines how precise you want the final solution to be. A load flow solution is considered reached if, between two iterations, the maximum bus voltage difference in per unit is less than the specified precision value.
Loading

Category
Select one of the 10 Loading Categories for this load flow study. The selection applies to all DC load elements and UPS.

Load Diversity Factor

None
Select Normal to use the percent loading of each load for the selected Loading Category.

Maximum
When the Maximum Loading option is selected, each load will be multiplied by the Maximum Load Diversity Factor entered in the Bus Editor for the bus where the load is connected.

This study option is helpful when the future loading of the electrical system has to be considered and each bus may be loaded at a different maximum value.

Minimum
When the Minimum Loading option is selected, each load will be multiplied by the Minimum Load Diversity Factor entered in the Bus Editor for the bus where the load is connected.

The minimum bus loading study option may be used to check system voltages under a minimum (light) loading condition.

Global Diversity Factor
When this option is selected, the Constant kVA and Constant Z edit boxes will be enabled, allowing you to enter the diversity factors in percent for constant kVA and constant impedance loads.

Note that these factors are global throughout the whole system. A motor load multiplying factor of 125% implies that the motor loads of all buses are increased by 25% above their nominal values. This value can be smaller or greater than 100%.

Constant kVA
Enter the global diversity factor in percent for constant kVA loads.

Constant Z
Enter the global diversity factor in percent for constant impedance loads.

Inverter Loading
There are two options for including inverter loads: operating load and loading category load.

Use Inverter Operating Load
Select this option to use the load displayed in the operating load section in the Loading page of the Inverter Editor. When the operating load is used, the diversity factor will not be applied to the inverter load. Note that these operating loading values can only be updated by running an AC load flow calculation. They cannot be edited directly by the user.
Use Inverter Loading Category
Select this option to use the loading category selected in the Category list.

Motor Load
A motor normally behaves as a constant power load when its terminal voltage is close to its rated voltage. However, when its terminal voltage deviates considerably from its rated voltage, its behavior becomes similar to a static load. This section allows you to set the voltage range within which you want a motor to be modeled as a constant power load.

Constant kW if V is within Range
Click on this check box for setting VMin and VMax. If this box is not checked, all of the motor loads will be modeled as constant power loads regardless of their terminal voltage. Please note that when only constant current sources in the system are present, this can prohibit load flow calculations from reaching a solution.

Vmin
Enter the minimum voltage in percent, below which the motor load will be modeled as a constant impedance load.

Vmax
Enter the maximum voltage in percent, above which the motor load will be modeled as a constant impedance load.

Initial Condition

Use Bus Voltages
Select this option to use the initial voltage value in the Bus Editor as the initial voltage in a load flow calculation. Please note that the bus initial voltage can be updated automatically in load flow studies.

Use Fixed Values
This option allows you to specify a flat initial voltage for all buses in a load flow calculation.

Report

Critical Voltage
Select this option and enter the minimum and maximum voltages that any bus may achieve before it is flagged and included in the critical undervoltage and overvoltage bus summary report.

Marginal Voltage
Select this option and enter the minimum and maximum voltages that any bus may achieve before it is flagged as a marginally undervoltage or overvoltage bus.

Bus Voltage
Calculated bus voltages seen in the output report can be printed in kV or in percent of the bus nominal voltages. Select your preference by clicking on Percent or kV.
**Update**
The selected options will be updated after the subsequent load flow run.

**Initial Bus Voltage**
Select this option to update the values of the bus voltage magnitudes with the result of this load flow run.

**Charger/UPS Operating Load**
Select this option to update the load provided by chargers/rectifiers. When a UPS is operating as a source to the DC system, its operating load will also be updated. The AC loads for these sources are calculated based on the DC power they provide, the losses involved, and their operating power factor.

**Remarks 2nd Line**
You can enter up to 120 alphanumeric characters in this remark box. Information entered here will be printed on the second line of every output report page header. These remarks can provide specific information regarding each study case. Note that the first line of the header information is global for all study cases and entered in the Project Information Editor.
25.3 Display Options

The DC Load Flow Analysis Display Options consist of a Results page and three pages for AC, AC-DC, and DC info annotations. Note that the colors and displayed annotations selected for each study are specific to that study.

25.3.1 Results Page

- **Color**
  Select a color from the drop down list for displaying calculation results on the one-line diagram.

- **Show Units**
  When this box is checked the unit for the calculation results will be displayed on the one-line diagram along with the results.

- **Voltage**
  
  - **Bus**
    Click on this check box to show the bus voltage in the one-line diagram.

  - **Bus Display Unit**
    From the drop down list box, you can select to display the bus voltage in percent or in volt.
**Power Flows**

**Power Flow Display Units**
Select to display the power flow in kW or MW.

**kW and Amp**
Select the kW to display power flow Amp to display current in ampere.

**% Voltage Drop**
Click on the Cable / Z check box to display voltage drop across cables and impedance.

**Branch Losses**
Click on the kW check box to display branch losses in kW.

**Elements**
Click on these check boxes to display load flow results for different types of elements, including Branch, Source, Load, Composite Motor, and Composite Network.

**25.3.2 AC Page**
This page includes options for displaying information annotations for AC elements.

**Color**
Select the color for information annotations to be displayed on the one-line diagram.

**ID**
Select the check boxes under this heading to display the ID of the selected AC elements on the one-line diagram.

**Rating**
Select the check boxes under this heading to display the ratings of the selected AC elements on the one-line diagram.

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen. (Generator)</td>
<td>kW / MW</td>
</tr>
<tr>
<td>Power Grid (Utility)</td>
<td>MVAsc</td>
</tr>
<tr>
<td>Motor</td>
<td>HP / kW</td>
</tr>
<tr>
<td>Load</td>
<td>kVA / MVA</td>
</tr>
<tr>
<td>Panel</td>
<td>Connection Type (# of Phases - # of Wires)</td>
</tr>
<tr>
<td>Transformer</td>
<td>kVA / MVA</td>
</tr>
<tr>
<td>Branch, Impedance</td>
<td>Base MVA</td>
</tr>
<tr>
<td>Branch, Reactor</td>
<td>Continuous Amps</td>
</tr>
<tr>
<td>Cable / Line</td>
<td># of Cables - # of Conductor / Cable - Size</td>
</tr>
<tr>
<td>Bus</td>
<td>kA Bracing</td>
</tr>
<tr>
<td>Node</td>
<td>Bus Bracing (kA)</td>
</tr>
<tr>
<td>CB</td>
<td>Rated Interrupting (kA)</td>
</tr>
<tr>
<td>Fuse</td>
<td>Interrupting (ka)</td>
</tr>
<tr>
<td>Relay</td>
<td>50/51 for Overcurrent Relays</td>
</tr>
</tbody>
</table>

Operation Technology, Inc. 25-9 PowerStation 4.0
kV
Select the check boxes under this heading to display the rated or nominal voltages of the selected elements on the one-line diagram.

For cables/lines, the kV check box is replaced by the button. Click on this button to display the cable/line conductor type on the one-line diagram.

A
Select the check boxes under this heading to display the ampere ratings (continuous or full-load ampere) of the selected elements on the one-line diagram.

For cables/lines, the Amp check box is replaced by the button. Click on this button to display the cable/line length on the one-line diagram.

Z
Select the check boxes under this heading to display the rated impedance of the selected AC elements on the one-line diagram.

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>Subtransient reactance Xd”</td>
</tr>
<tr>
<td>Power Grid (Utility)</td>
<td>Positive Sequence Impedance in % of 100 MVA (R + j X)</td>
</tr>
<tr>
<td>Motor</td>
<td>% LRC</td>
</tr>
<tr>
<td>Transformer</td>
<td>Positive Sequence Impedance (R + j X per unit length)</td>
</tr>
<tr>
<td>Branch, Impedance</td>
<td>Impedance in ohms or %</td>
</tr>
<tr>
<td>Branch, Reactor</td>
<td>Impedance in ohms</td>
</tr>
<tr>
<td>Cable / Line</td>
<td>Positive Sequence Impedance (R + j X in ohms or per unit length)</td>
</tr>
</tbody>
</table>

D-Y
Select the check boxes under this heading to display the connection types of the selected elements on the one-line diagram.

For transformers, the operating tap setting for primary, secondary, and tertiary windings are also displayed. The operating tap setting consists of the fixed taps plus the tap position of the LTC.

Composite Motor
Click on this check box to display the AC composite motor IDs on the one-line diagram, then select the color in which the IDs will be displayed.

Use Default Options
Click on this check box to use PowerStation’s default display options.

25.3.3 AC-DC Page
This page includes options for displaying info annotations for AC-DC elements and composite networks.

Color
Select the color for information annotations to be displayed on the one-line diagram.
DC Load Flow Analysis  Display Options

ID
Select the check boxes under this heading to display the IDs of the selected AC-DC elements on the one-line diagram.

Rating
Select the check boxes under this heading to display the ratings of the selected AC-DC elements on the one-line diagram.

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charger</td>
<td>AC kVA &amp; DC kW (or MVA / MW)</td>
</tr>
<tr>
<td>Inverter</td>
<td>DC kW &amp; AC kVA (or MW / MVA)</td>
</tr>
<tr>
<td>UPS</td>
<td>kVA</td>
</tr>
<tr>
<td>VFD</td>
<td>HP / kW</td>
</tr>
</tbody>
</table>

kV
Click on the check boxes under this heading to display the rated or nominal voltages of the selected elements on the one-line diagram.

A
Click on the check boxes under this heading to display the ampere ratings of the selected elements on the one-line diagram.

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Amp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charger</td>
<td>AC FLA &amp; DC FLA</td>
</tr>
<tr>
<td>Inverter</td>
<td>DC FLA &amp; AC FLA</td>
</tr>
<tr>
<td>UPS</td>
<td>Input, output, &amp; DC FLA</td>
</tr>
</tbody>
</table>

Composite Network
Click on this check box to display the composite network IDs on the one-line diagram, then select the color in which the IDs will be displayed.

Use Default Options
Click on this check box to use PowerStation’s default display options.

25.3.4 DC Page
This page includes options for displaying info annotations for DC elements.

Color
Select the color for information annotations to be displayed on the one-line diagram.

ID
Select the check boxes under this heading to display the IDs of the selected DC elements on the one-line diagram.
DC Load Flow Analysis  Display Options

Rating
Select the check boxes under this heading to display the ratings of the selected DC elements on the one-line diagram.

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>Ampere Hour</td>
</tr>
<tr>
<td>Motor</td>
<td>HP / kW</td>
</tr>
<tr>
<td>Load</td>
<td>kW / MW</td>
</tr>
<tr>
<td>Elementary Diagram</td>
<td>kW / MW</td>
</tr>
<tr>
<td>Converter</td>
<td>kW / MW</td>
</tr>
<tr>
<td>Cable</td>
<td># of Cables - # of Conductor / Cable - Size</td>
</tr>
</tbody>
</table>

kV
Select the check boxes under this heading to display the rated or nominal voltages of the selected elements on the one-line diagram.

For cables, the kV check box is replaced by the button. Click on this button to display the conductor type on the one-line diagram.

A
Select the check boxes under this heading to display the ampere ratings of the selected elements on the one-line diagram.

For cables, the Amp check box is replaced by the button. Click on this button to display the cable length (one way) on the one-line diagram.

Z
Select the check boxes under this heading to display the impedance values of the cables and impedance branches on the one-line diagram.

Composite Motor
Click on this check box to display the DC composite motor IDs on the one-line diagram, then select the color in which the IDs will be displayed.

Use Default Options
Click on this check box to use PowerStation’s default display options.
25.4 Calculation Methods

The PowerStation DC Load Flow calculation is an iterative process, due to the presence of constant power loads and power converter components. The objective of a load flow calculation is to find bus voltage values with specified system loads and sources. Based on the obtained bus voltage results, branch flows can then be calculated. The Newton-Raphson method is used in solving DC load flow calculations. This method is fast in convergence speed, but it has a relatively high requirement on initial bus voltage values.

In a DC load flow calculation, the loads involved in the system are constant power loads and constant impedance loads. The sources include constant voltage source and constant current source. A constant voltage source maintains its terminal bus voltage at a fixed value, while a constant current source injects a fixed value of current into the system.

Because a converter component, such as a charger, has a maximum current limit, it is a constant voltage source only when its output current is not larger than its current limit. Once the output current is over the limit, it becomes a current source. Therefore, the operating mode of a converter component and its model cannot be predefined. It varies depending on system loads and configurations, and is determined during the process of calculation.

**Newton-Raphson Method**

The Newton-Raphson method formulates and solves iteratively the following load flow equation:

\[ J \times \Delta V = \Delta I \]

where \( \Delta I \) is a vector for bus current injection mismatch between the specified value and the calculated value. Here the constant power loads are converted to current injections using the calculated voltage. \( \Delta V \) is a vector for bus voltage incremental and \( J \) is a coefficient matrix called the Jacobian matrix.

The Newton-Raphson method possesses a unique quadratic convergence characteristic. It usually has a very fast convergence speed compared to other load flow calculation methods. However, the method is highly dependent of the initial value of bus voltages. A careful selection of bus voltage initial values is strongly recommended.

It should be noted that when the system contains constant power loads and a charger (or a UPS) is the only source in the system, if the source is overloaded and it changes to a constant current source, there may be problems in reaching a solution. This can occur when the source switches to a constant current source, it provides less current than it would as a constant voltage source. For a constant power load, its terminal voltage increases when it draws less current in order to maintain a constant power. It can lead to abnormally high voltage values as the calculation resolves. At such high voltage values, the motor loads actually behave as constant impedance loads. In order to resolve this situation, you may check the option of Constant kW if V within Range in the study case and properly set the VMin and VMax values.
25.4.1 Component Models and Operations

Charger

Model
In DC load flow calculations, a charger can be represented in one of three models: constant voltage source model, constant current source model, and inactive mode model.

A charger is normally operating as a constant voltage source, maintaining its terminal bus voltage at the regulated value specified in the Charger Editor. However, when the current drawn from the charger is more than $I_{\text{max}}$, the maximum current it can provide while keeping its terminal voltage constant at the same time, it becomes a constant current source. The current drawn from the charger is then kept at $I_{\text{max}}$, while the terminal voltage drifts, depending on system loads and other sources.

Whenever the terminal bus voltage is lower than the regulated voltage of a charger, it will try to raise the voltage to the regulated value until the charger current reaches $I_{\text{max}}$. On the contrary, if for some reason, such as other sources being connected to the same buses, the terminal bus voltage is higher than the charger regulated voltage, the charger becomes inactive as if it is switched off from the system.

Operating Mode
As a constant voltage source, a charge can operate in either the Constant Vdc mode or the Fixed Firing Angle mode, depending on the selection made in the Rating page of the Charger Editor.

In the Constant Vdc mode, the charger output voltage is regulated at either the floating voltage or the equalizing voltage, as selected in the Rating page of the Charger Editor.

In the Fixed Firing Angle mode, the output voltage depends on the firing angle and the input bus voltage value. When the load to the charge varies, its output voltage should change accordingly. However, since the internal voltage drop of a charger is not considered in the calculation, the charger output voltage is assumed to be constant in the load flow studies.

Converter
From the Information page of the Charger Editor, you may select the type of charger as Converter, which means it is actually a rectifier. As a rectifier, it behaves almost the same as a charger, except that it does not have floating and equalizing voltage values. When operating in the Constant Vdc mode, the regulated voltage is equal to its rated output voltage.

UPS

UPS as Source or Load
To the DC system, a UPS (Uninterruptible Power Supply) can be a source or a load. When a UPS is connected to an energized input AC bus and it does not have an auction diode (the Auction Diode option in the Rating page of the UPS Editor is not checked), it is considered as a source to the DC system.

When a UPS is not connected to an energized AC input bus, it becomes a load to the DC system.
When a UPS is connected to an energized input AC bus, but it has an auction diode, the diode prevents the flow from entering into the DC system, so the UPS will not be a source to the DC system. In this case, either the DC system or the AC input bus may provide the power to loads connected to the UPS output AC bus, depending on the voltage values of the AC input bus and the DC bus. After converting to the UPS AC output terminal using the UPS rated voltage ratio, if the DC bus voltage is higher than the AC bus voltage, the DC system will provide the power to the UPS output load; otherwise, the AC input bus provides the power to the load.

**UPS as Source to the DC System**

When operating as a source to the DC system, a UPS behaves very similarly to a charger. It can be represented in one of three models: constant voltage source model, constant current source model, and inactive mode model.

As a source, a UPS is normally operating as a constant voltage source, maintaining its terminal bus voltage at its rated voltage. However, when the current drawn from the UPS is more than $I_{max}$, the maximum current it can provide while keeping its terminal voltage constant at the same time, it becomes a constant current source. The current drawn from the UPS is then kept at $I_{max}$, while the terminal voltage drifts, depending on system loads and other sources.

Whenever the terminal bus voltage is lower than the regulated voltage of a UPS, it will try to raise the voltage to the regulated value, until the UPS current reaches $I_{max}$. On the contrary, if for some reason, such as other sources being connected to the same buses, the terminal bus voltage is higher than the charger regulated voltage, the UPS becomes inactive as if it is switched off from the system.

**Constant Voltage Source Operating Mode**

As a constant voltage source, a UPS can operate in either the Constant Vdc mode or the Fixed Firing Angle mode, depending on the selections made in the Rating page of the UPS Editor.

In the Constant Vdc mode, the UPS output voltage is regulated at its rated DC voltage.

In the Fixed Firing Angle mode, the output voltage depends on the firing angle and the input bus voltage value. When the load to the charge varies, its output voltage should change accordingly. However, since the internal voltage drop of a UPS is not considered in the calculation, the UPS output voltage is assumed to be constant in load flow studies.

**UPS as Load to the DC System**

When a UPS is a load to the DC system, it is a constant kW load. The loading category load is used in load flow studies.

**Battery**

Under normal operation conditions, a battery serves as a back up source. It actively provides power to loads only when other sources, such as chargers, become de-energized or fail to maintain system voltage at the required level.

In DC load flow analyses, a battery can be represented in one of two models: a constant voltage source model and an inactive mode model. When the terminal bus voltage is higher or equal to the rated voltage of a battery, it is in the inactive mode and is not supplying any power to the system. A battery that has just been discharged is actually a load to the DC system. Due to the complexity in determining quantitatively the load for a charging battery, it is not considered as a load in the DC load flow analysis. It is considered in the battery sizing calculation.
When the terminal bus voltage of a battery is lower than its rated voltage, the battery becomes an active source. It is represented by a constant voltage source (at battery rated voltage) behind battery resistance.

**DC Converter**

A DC converter can change DC voltage from one level to another, either increasing or decreasing the voltage value. It has the capability of regulating the output voltage as long as it is not overloaded. It is unidirectional in terms of power flow, allowing the current flowing from the input terminal to the output terminal only.

In DC load flow calculations, a DC converter can be represented in one of three models: constant voltage source model, constant current source model, and inactive mode model.

A DC converter is normally operating as a constant voltage source, maintaining its terminal bus voltage at the regulated value specified in the DC converter editor. However, when the current drawn from the DC converter is more than $I_{\text{max}}$, the maximum current it can provide while keeping its terminal voltage constant at the same time, it becomes a constant current source. The current drawn from the DC converter is then kept at $I_{\text{max}}$ while the terminal voltage drifts, depending on system loads and other sources.

Whenever the terminal bus voltage is lower than the regulated voltage of a DC converter, it will try to raise the voltage to the regulated value, until the DC converter current reaches $I_{\text{max}}$. On the contrary, if for some reason, such as other sources being connected to the same buses, the terminal bus voltage is higher than the DC converter regulated voltage, the DC converter becomes inactive as if it is switched off from the system.

When a DC converter is operating as a source, either a constant voltage source or a constant current source, it is a constant power load to its input bus, with a load equal to output power plus converter losses.

**25.4.2 Factors Considered in DC Load Flow Calculations**

**Load Flow Convergence**

Due to the iterative process used for solving load flow and the Newton-Raphson method used, DC load flow may have convergence problems for some ill-conditioned systems and some special operating conditions.

Consider a system that contains motor loads and a charger (or a UPS) as the only source in the system. If the source is overloaded and it changes to a constant current source, there may be problems in reaching a solution. This is because when the source switches to a constant current source, it provides less current than it would as a constant voltage source. For a constant power load, its terminal voltage increases when it is drawing less current in order to maintain a constant power. It can lead to abnormally high voltage values and causes the calculation process to fail to converge.

In the real world, at such high voltage values, the motor loads actually behave as constant impedance loads. In order to resolve this situation, the DC load flow study case provides you with the opportunity to set a voltage range for motor loads to be modeled as constant power loads. In the DC Load Flow Study Case Editor, you can check the option of Constant kW if V within Range and properly set the VMin and VMax values. Once the motor terminal voltage is outside this range, the motor will be modeled as a constant impedance load. However, inverter or UPS loads are always modeled as constant power loads.
25.5 Required Data

25.5.1 Source

**Charger**

*Info Page*
- Charger ID
- Bus connection data

*Rating Page*
- All data in this page are required for DC load flow calculations

**UPS**

*Info Page*
- UPS ID
- Bus connection data

*Rating Page*
- All data in this page are required for DC load flow calculations

*Loading Page*
- Loading data. If a UPS is a load to the DC system, that is, when the it is not connected to an energized AC input bus or the Auction Diode option in the Rating page is checked, the data entered is used to determine the UPS load to the DC system.

**Battery**

*Info Page*
- Battery ID
- Bus connection data
- Number of strings
- Battery Library type data. The resistance per positive plate (Rp) is used to calculate battery internal resistance.

*Rating Page*
- Number of cells
- Rated voltage

**SC Page**
- External resistance R
25.5.2 Load

**DC Motor**

- **Info Page**
  - Motor ID
  - Bus connection data
  - Configuration status
  - Demand factor
  - Quantity

- **Rating Page**
  - Rating section data
  - Load category data

**Lumped Load**

- **Info Page**
  - Lumped load ID
  - Bus connection data
  - Configuration status
  - Demand factor

- **Rating Page**
  - Rating section data
  - Motor/static load percent
  - Load category data

**Static Load**

- **Info Page**
  - Static load ID
  - Bus connection data
  - Configuration status
  - Demand factor
  - Quantity

- **Rating Page**
  - Rating section data
  - Load category data
DC Load Flow Analysis

**ED Load**

**Info Page**
- ED load ID
- Bus connection data

**Rating Page**
- Rating section data
- Load category data

**Inverter**

**Info Page**
- Inverter ID
- Bus connection data
- Configuration status
- Demand factor

**Rating Page**
- AC rating section data
- DC rating section data

**Loading Page**
- Loading category data

**25.5.3 Branch**

**DC Cable**

**Info Page**
- Cable ID
- Bus connection data
- Cable length
- Number of cables per phase

**Impedance Page**
- Cable resistance
- Units section data
- Base and maximum operating temperature
DC Load Flow Analysis

Required Data

**DC Impedance**

**Info Page**
- DC impedance ID
- Bus connection data
- Impedance resistance

**Tie PD (CB, Fuse, Single-Throw & Double-Throw Switches)**

**Info Page**
- ID
- Bus connection data
- Configuration status

**25.5.4 DC Converter**

**Info Page**
- DC converter ID
- Bus connection data

**Rating Page**
- Rating section data
- Operating $V_{out}$

**25.5.5 Study Case**

Similar to any other study, you are always required to run a DC load flow calculation. When a DC load flow calculation is initiated by the user, PowerStation uses the study case currently showing in the study case editor for the calculation. Every field in a study case has its default value. However, it is important to set the values correctly in the study case to meet your calculation requirements.
25.6 Output Reports

The DC load flow calculation results are reported both on the one-line diagram and in the Crystal Reports format. The graphical one-line diagram displays the calculated bus voltages, branch flows and voltage drops, load power consumption, etc. You can use the Display Options Editor to specify the content to be displayed. It also flags abnormal operating conditions, such as overloaded cables and over- or undervoltage buses, in different colors.

The Crystal Reports format provides you with detailed information for a DC load flow analysis. You can utilize the DC Load Flow Report Manager to help you view the output report.

25.6.1 DC Load Flow Report Manager

To open the DC Load Flow Report Manager, simply click on the View Report File button on the DC Load Flow Toolbar. The editor includes four pages (Complete, Input, Result, and Summary) representing different sections of the output report. The Report Manager allows you to select formats available for different portions of the report and view it via Crystal Reports. There are several fields and buttons common to every page, as described below.

Output Report Name
This field displays the name of the output report you want to view.

Project File Name
This field displays the name of the project file based on which report was generated, along with the directory where the project file is located.

Help
Click on this button to access Help.

OK / Cancel
Click on the OK button to dismiss the editor and bring up the Crystal Reports view to show the selected portion of the output report. If no selection is made, it will simply dismiss the editor. Click on the Cancel button to dismiss the editor without viewing the report.

Complete Page
In this page there is only one format available, Complete, which brings up the complete report for the DC load flow study. The complete report includes input data, results, and summary reports.
Input Data Page
This page allows you to select different formats for viewing input data, grouped according to type. They include:

- Battery
- Branch Connection
- Bus
- Cable
- Charger
- Cover
- DC Converter
- Impedance
- Inverter
- Loads
- UPS

Result Page
This page allows you to select formats to view the load flow result portion of the output report.
Summary Page
This page allows you to select different portions of the load summary to view. Note that some portions of the summary are available only when you selected specific options in the study case, such as Critical and Marginal Voltage options.

Branch Flow Summary
Overvoltage & Undervoltage Buses
Summary
Total Sources and Demands

25.6.2 View Output Reports From Study Case Toolbar
This is a shortcut for the Report Manager. When you click on the View Output Report button, PowerStation automatically opens the output report, which is listed in the Study Case Toolbar with the selected format. In the picture shown below, the output report name is RPT-200X and the selected format is Summary.
25.6.3 Input Data

Input data are grouped together according to element type. The following are some samples of input data.

**Bus Input Data**

<table>
<thead>
<tr>
<th>Bus Info. &amp; Nominal V</th>
<th>Initial V</th>
<th>Nominal Load (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Type</td>
<td>V</td>
</tr>
<tr>
<td>Dc Bus1</td>
<td>Voltage Reg.</td>
<td>250.00</td>
</tr>
<tr>
<td>Dc Bus2</td>
<td>Load</td>
<td>250.00</td>
</tr>
<tr>
<td>Dc Bus3</td>
<td>Load</td>
<td>125.00</td>
</tr>
<tr>
<td>Dc Bus4</td>
<td>Voltage Reg.</td>
<td>125.00</td>
</tr>
<tr>
<td>Dc Bus5</td>
<td>Load</td>
<td>250.00</td>
</tr>
</tbody>
</table>

**Cable & Impedance Input Data**

<table>
<thead>
<tr>
<th>Cable</th>
<th>Connected Buses</th>
<th>Ohm per 1000 ft / Copper Conductor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>From</td>
<td>To</td>
</tr>
<tr>
<td>Cable 15</td>
<td>Dc Bus1</td>
<td>Dc Bus2</td>
</tr>
<tr>
<td>Cable 16</td>
<td>Dc Bus3</td>
<td>Dc Bus4</td>
</tr>
</tbody>
</table>

Line/Cable resistance are listed at the specified temperature.

**Impedance Input Data**

<table>
<thead>
<tr>
<th>Impedance</th>
<th>Connected Buses</th>
<th>Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>From</td>
<td>To</td>
</tr>
<tr>
<td>DcImp1</td>
<td>Dc Bus3</td>
<td>Dc Bus4</td>
</tr>
</tbody>
</table>
### Converter Input Data

#### CHARGER Input Data

<table>
<thead>
<tr>
<th></th>
<th>Charger</th>
<th>AC</th>
<th>DC</th>
<th>Operating Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>500,0</td>
<td>40</td>
<td>390,50</td>
<td>390,00</td>
</tr>
</tbody>
</table>

#### UPS Input Data

<table>
<thead>
<tr>
<th>UPS</th>
<th>AC</th>
<th>DC</th>
<th>Operating Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>400,0</td>
<td>50</td>
<td>390,00</td>
</tr>
</tbody>
</table>

#### DC CONVERTER Input Data

<table>
<thead>
<tr>
<th>DC Converter</th>
<th>Rating Parameters</th>
<th>Operating</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Vdc</td>
<td>Vdc</td>
</tr>
<tr>
<td>DCConv1</td>
<td>250,0</td>
<td>250,00</td>
</tr>
</tbody>
</table>

### Load Input Data

#### LOADS

<table>
<thead>
<tr>
<th>Load Info.</th>
<th>Connected Bus</th>
<th>Rating Parameters</th>
<th>Operating Load (kW) *</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Type</td>
<td>Nom. V</td>
<td>FLA in</td>
</tr>
<tr>
<td>DCED1</td>
<td>Ed Load</td>
<td>280,0</td>
<td>280,00</td>
</tr>
<tr>
<td>DCED2</td>
<td>Bus1</td>
<td>250,0</td>
<td>250,00</td>
</tr>
<tr>
<td>DCED3</td>
<td>Bus2</td>
<td>250,0</td>
<td>250,00</td>
</tr>
<tr>
<td>DClamp1</td>
<td>Dimp</td>
<td>250,0</td>
<td>250,00</td>
</tr>
<tr>
<td>DCMotor1</td>
<td>Motor</td>
<td>250,0</td>
<td>250,00</td>
</tr>
</tbody>
</table>

* Notes:
- The Operating Load includes % Leading, Demand Factor, and Load Diversity Factor for each individual load.
- M Load includes % Leading and Demand Factor.
25.6.4 Load Flow Results
The result section of the output report includes the calculated results of a DC load flow analysis, including bus voltage, bus loading, and branch flows.

**LOAD FLOW Report**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Type</td>
<td>V</td>
<td>%</td>
</tr>
<tr>
<td>DeBus1</td>
<td>Load</td>
<td>250.0</td>
<td>100.2</td>
</tr>
<tr>
<td>DeBus2</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>DeBus3</td>
<td>Load</td>
<td>250.0</td>
<td>100.2</td>
</tr>
<tr>
<td>DeBus1</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>DCCont</td>
<td>65.028</td>
<td>20.210</td>
<td></td>
</tr>
<tr>
<td>DCInstl</td>
<td>-102.056</td>
<td>-78.64</td>
<td></td>
</tr>
<tr>
<td>DCInstl</td>
<td>-102.056</td>
<td>-78.64</td>
<td></td>
</tr>
<tr>
<td>DeBus4</td>
<td>Load</td>
<td>125.0</td>
<td>50.4</td>
</tr>
<tr>
<td>DeBus3</td>
<td>19.921</td>
<td>156.37</td>
<td></td>
</tr>
<tr>
<td>Up1</td>
<td>-59.260</td>
<td>-428.63</td>
<td></td>
</tr>
<tr>
<td>DCCont</td>
<td>-59.260</td>
<td>-428.63</td>
<td></td>
</tr>
<tr>
<td>DCInstl</td>
<td>300.000</td>
<td>200.69</td>
<td></td>
</tr>
<tr>
<td>DeBus5</td>
<td>Load</td>
<td>250.0</td>
<td>100.4</td>
</tr>
<tr>
<td>DeBus3</td>
<td>80.556</td>
<td>304.16</td>
<td></td>
</tr>
<tr>
<td>Inv1</td>
<td>25.000</td>
<td>100.69</td>
<td></td>
</tr>
<tr>
<td>DCInstl</td>
<td>55.556</td>
<td>333.36</td>
<td></td>
</tr>
</tbody>
</table>

25.6.5 Summary Reports
The load flow summary portion of the output report includes the branch flow summary, the bus over-/undervoltage summary, and the summary of total system sources and demands.

**BRANCH FLOW Summary Report**

<table>
<thead>
<tr>
<th>Branch Information</th>
<th>Connected Bus</th>
<th>Branch Flow</th>
<th>%Bus Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Type</td>
<td>From Bus ID</td>
<td>To Bus ID</td>
</tr>
<tr>
<td>Cable-13</td>
<td>Cable</td>
<td>DeBus1</td>
<td>DeBus2</td>
</tr>
<tr>
<td>Cable-12</td>
<td>Cable</td>
<td>DeBus3</td>
<td>DeBus4</td>
</tr>
<tr>
<td>DCInstl</td>
<td>Inj-Ganc</td>
<td>DeBus3</td>
<td>DeBus4</td>
</tr>
</tbody>
</table>

**UNDEEENTIAL BUS Summary Report**

<table>
<thead>
<tr>
<th>Bus</th>
<th>Oper. Voltage</th>
<th>% Mofg</th>
</tr>
</thead>
<tbody>
<tr>
<td>DeBus3</td>
<td>125.00</td>
<td>99.37</td>
</tr>
</tbody>
</table>

Note: * indicates bus voltages below critical limit
* indicates bus voltages below marginal limit