POWERFACTORY

# PowerFactory 2021

## Technical Reference

### Step-Voltage Regulator

ElmVoltreg, TypVoltreg

PF2021

POWER SYSTEM SOLUTIONS
MADE IN GERMANY

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# Contents

# 1 General Description

Voltage regulators are used to regulate the voltage in distribution feeders to maintain voltage within predefined limits.

A voltage regulator is an autotransformer with on-load tap changer. The autotransformer includes a shunt and a series winding. The tap changer of a voltage regulator is located in the series winding. Typically, the voltage regulation range is ±10% subdivided in 32 steps. Step-voltage regulators can be classified as Type A or Type B according to ANSI/IEEE C57.15, depending on the location of the shunt winding. In Type A regulators the shunt winding is connected across the source side, while it is connected across the load side in Type B regulators.

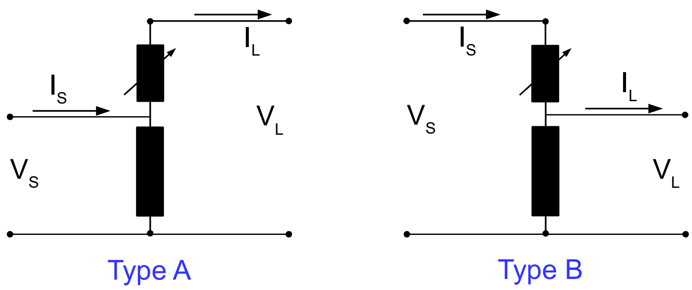



Figure 1.1: Single-phase circuit diagram of Type A and Type B regulators

Depending on the configuration, three or two single-phase voltage regulators are connected to form a three-phase voltage regulator unit. Each single-phase regulator has its own tap controller independently controlling its tap position. Only three-phase voltage regulators are supported in *PowerFactory*. Single-phase elements are not supported.

Information regarding step-voltage regulator configuration, type, connection, ratings, tap changer and series-impedance are entered in the Step-Voltage Regulator Type (*TypVoltreg*).

The terminal connected to the source will be referred to as Source-side terminal and the terminal connected to the load as Load-side terminal.

# 2 Configuration

The following configurations are supported:

- Star, 3-phase
- Star, 3 x 1-phase
- Closed delta, 3 x 1-phase
- Open delta, 2 x 1-phase

## 2.1 Star, 3-phase

This configuration models a three-phase star-connected regulator with only one tap controller. Therefore, the tap positions on the three phases are operated together. The regulator nominal voltage refers to the line-line voltage. If selected in the element, the automatic tap controller can be set to control a phase-to-ground, a line-line or the positive sequence voltage. The star configuration is shown in Figure 2.1, where capital letters refer to the Source-side and lower-case letters refer to the Load-side.

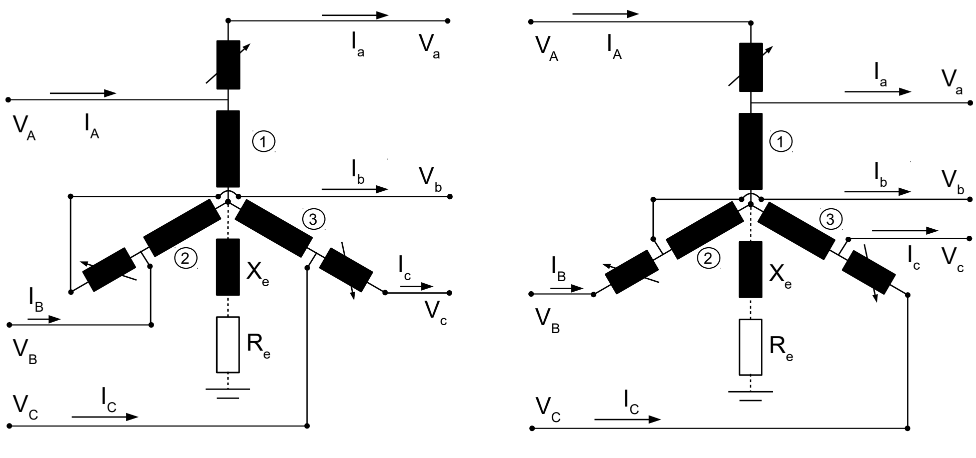



Figure 2.1: Star configuration

The star configuration can be grounded through an impedance $Z_e$ or ungrounded. A neutral conductor can be defined as well, as shown in Figure 2.2. When a neutral connection *At Terminals (ABC-N)* is selected, a connection is done for both the Source-side and the Load-side. Grounding (not shown in the figure) through $Z_e$ is also possible in this case. In the case of a neutral connection at a *Separate* terminal, a connection is created to the selected terminal and grounding is not possible. These settings can be defined in the *Basic Data* page under the *Grounding/Neutral Conductor* tab.

## 2.2 Star, 3 x 1-phase

This configuration, see Figure 2.1, models three single-phase star-connected regulators, each with an independent tap controller. The main difference compared with the "Star, 3-phase"

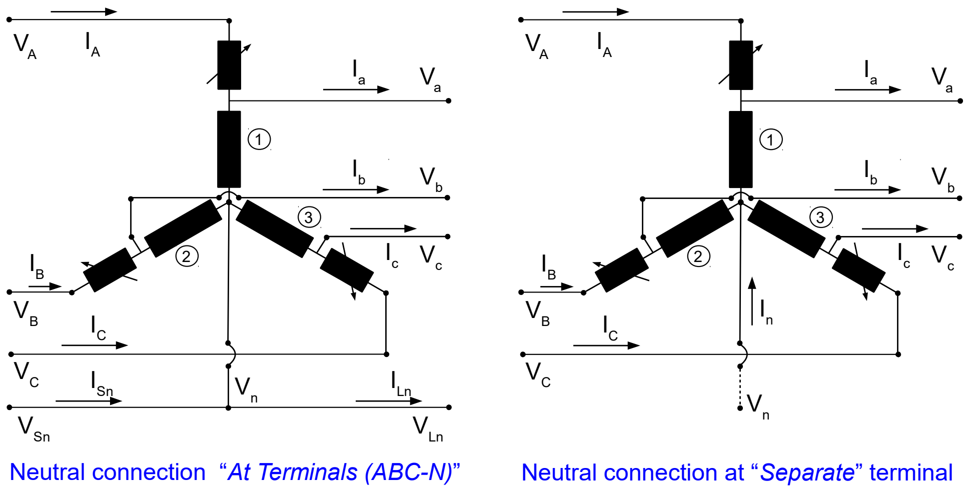



Figure 2.2: Star configuration with neutral connection (Type B)

configuration is that the tap positions on the three phases are controlled independently of each other. The regulator nominal voltage refers to the line-neutral voltage. If the automatic tap controller is selected in the element, each controller controls its own Load-side phase-neutral voltage. The inbuilt current transformers measure the Load-side current. The inbuilt voltage transformers measure the Load-side phase-neutral voltages.

## 2.3 Closed Delta, 3 x 1-phase

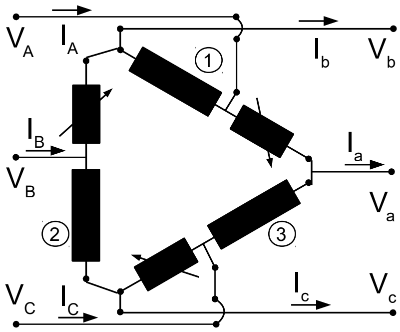
This configuration models three single-phase closed delta-connected regulators, each with an independent tap controller. Therefore the tap positions of the three regulators are controlled independently of each other. The regulator nominal voltage refers to the line-line voltage. If the automatic tap controller is selected in the element, each controller controls its own Load-side line-line voltage. The inbuilt current transformers measure the current out of each regulator, which is not the Load-side current. The inbuilt voltage transformers measure the Load-side line-line voltages.

If each single-phase voltage regulator has $\pm 10\%$ voltage regulation range, the maximum change in the Load-side voltage achievable with a closed delta regulator is about $\pm 15\%$ (see Figure 2.4).

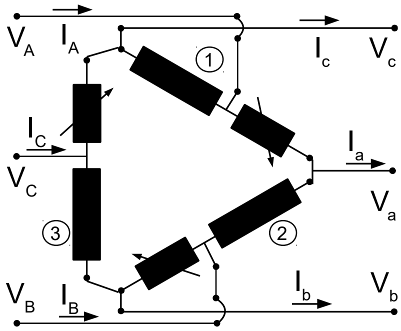
Notice that even if the three tap controllers are independent, for a closed delta regulator changing one tap affects the voltage in all phases.

### 2.3.1 Available Connections

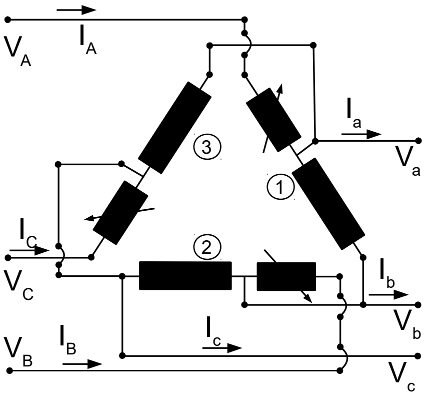
A closed delta step-voltage regulator can be connected in two ways: Positive phase rotation (Lagging) and Negative phase rotation (leading). The different connection schemes for Type A and Type B regulators and for Positive and negative phase rotation are shown in Figure 2.3.



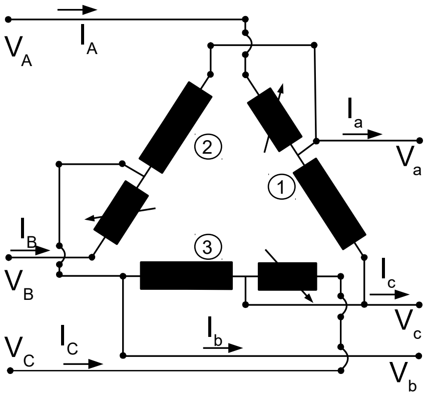

Type A, Positive phase rotation




Type A, Negative phase rotation



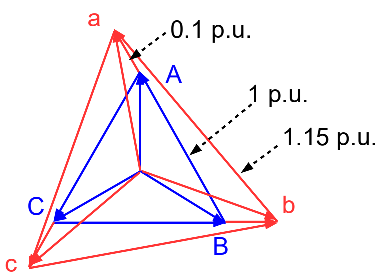

Type B, Positive phase rotation



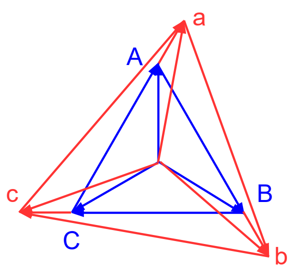

Type B, Negative phase rotation

Figure 2.3: Closed delta configuration

The resulting voltage vector diagrams (when all three taps are at the same increasing position) for Positive and Negative phase rotation are shown in Figure 2.4.




Positive phase rotation




Negative phase rotation

Figure 2.4: Closed delta voltage diagram. All three regulators at maximum tap position

For Positive phase rotation connection, the Load-side phase-neutral (a fictitious neutral) voltages are ahead of the phase-neutral voltages on the Source-side. Assuming a pure resistive current (in phase with the phase-neutral voltage on the Source-side), on the Load-side the current is lagging the voltage. For Negative phase rotation connection, the Load-side phase-neutral (a fictitious neutral) voltages are behind the phase-neutral voltages on the Source-side. Assuming a pure resistive current (in phase with the phase-neutral voltage on the Source-side), on the Load-side the current is leading the voltage.

## 2.4 Open Delta, 2 x 1-phase

This configuration models two single-phase open delta-connected regulators, each with an independent tap controller. Therefore, the tap positions of the two regulators are controlled independently of each other. The regulator nominal voltage refers to the line-line voltage. If the automatic tap controller is selected in the element, each controller controls its own Load-side line-line voltage. In the open delta connection, the inbuilt current transformers are measuring the Load-side current. The inbuilt voltage transformers measure the Load-side line-line voltages.

As the open delta configuration cannot be represented in symmetric calculations, it is replaced in these calculations by a star-connected voltage regulator.

### 2.4.1 Available Connections

Two voltage regulators can be connected in open delta between different phases. ”AB - CB”, ”AC - BC” and ”BA - CA” are possible connections. For example, the connection ”AB - CB” indicates that one single-phase voltage regulator is connected between phases A and B and the other single-phase voltage regulator is connected between phases C and B.

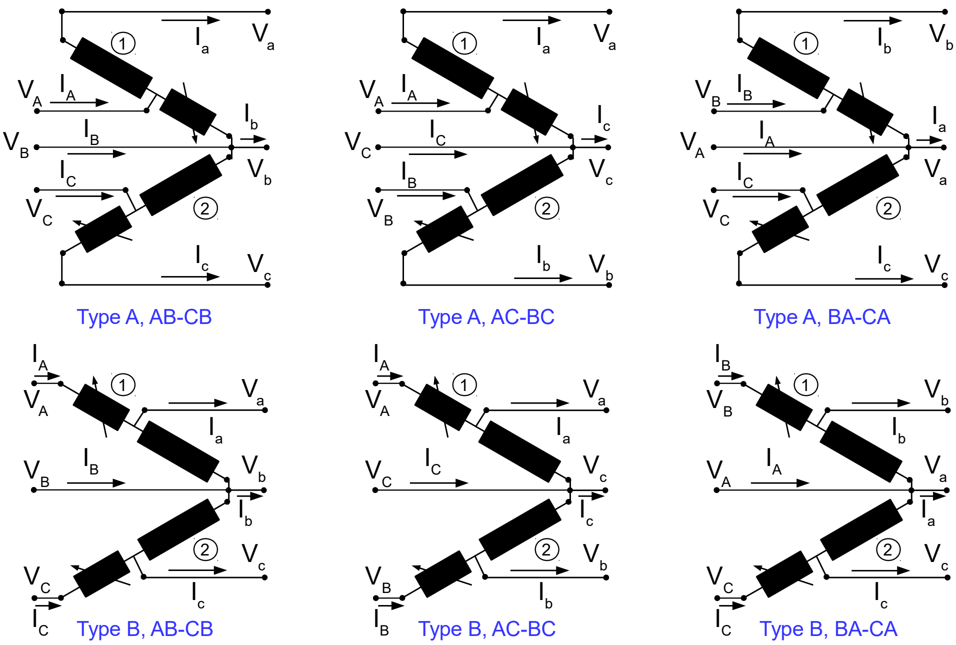



Figure 2.5: Open delta configuration

As can be seen from Figure 2.6 an equal increase in the two voltage regulators connected in open delta results in a symmetric increase in all line-line voltages.

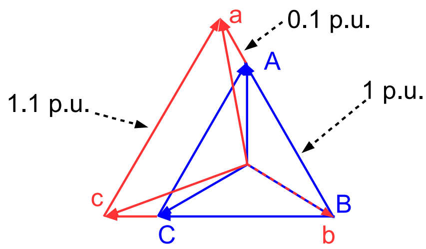



Figure 2.6: Open delta voltage diagram for AB-CB connection. The two regulators are at maximum tap position

# 3 Rating

Given the rated current (in A) and the rated voltage (in kV) of a three-phase circuit, the circuit rated power (in kVA) is calculated according to:

$$S_{circuit} = \sqrt{3} \cdot U_{n,l-l} \cdot I_n \qquad \text{in kVA} \tag{1}$$

The voltage regulator rated current $I_n$ is equal to the load current. Notice that this is also valid for voltage regulators in closed or open delta connection. The rated voltage $U_n$ matches the system line-line voltage for single-phase regulators connected in closed or open delta or for a three-phase regulator (configuration ”Star, 3-phase”), but it matches the system line-neutral voltage for single-phase regulators star-connected (configuration ”Star, 3 x 1-phase”).

The rated power of a voltage regulator is calculated taking into account the voltage regulation range. The rated power $S_n$ of a single-phase voltage regulator (forming a ”Star, 3 x 1-phase”, ”Closed delta, 3 x 1-phase” or ”Open Delta, 2 x 1-phase” configuration) is calculated as:

$$S_n = U_n \cdot I_n \cdot \frac{\text{Voltage regulation range (in \%)}}{100} \qquad \text{in kVA} \tag{2}$$

The rated power $S_n$ of a three-phase voltage regulator (configuration ”Star, 3-phase”) is calculated as:

$$S_n = \sqrt{3} \cdot U_n \cdot I_n \cdot \frac{\text{Voltage regulation range (in \%)}}{100} \qquad \text{in kVA} \tag{3}$$

The circuit base power $S_b$ is calculated for both single-phase and three-phase voltage regulators as:

$$S_b = S_n \cdot \frac{100}{\text{Voltage regulation range (in \%)}} \qquad \text{in kVA} \tag{4}$$

The circuit base power is higher than the voltage regulator rated power.

In the type *TypVoltreg*, the calculated rated power refers to the single-phase voltage regulators which form the chosen three-phase configuration. Only for the ”Star, 3-phase” configuration, does the shown rated power indicate the three-phase rating.

# 4 Series Impedance

Typically the series impedance of voltage regulators is very small and it can often be neglected. In *PowerFactory* step-voltage regulator models, the series impedance is always assumed to be connected on the Source-side, i.e. the voltage drop over the series-impedance is equal to the impedance times the Source-side current, see Figure 4.1.

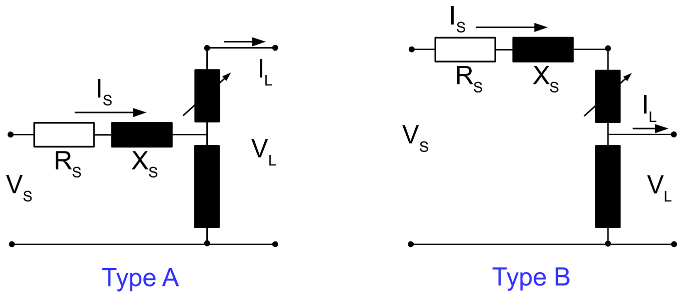



Figure 4.1: Type A and Type B regulators with series impedance

The series-impedance can be defined in the type *TypVoltreg* by one of the following pairs of values:

- Short-circuit voltage uk in % and Copper losses in kW
- Short-circuit voltage uk in % and SHC voltage (Re(uk)) ukr in %
- Short-circuit voltage uk in % and X/R ratio
- Reactance x in p.u. and Resistance r in p.u.

In the type it is also possible to define a tap dependency for the series impedance.

The series-impedance is always specified in terms of the circuit base power, which is equal to the voltage regulator rated power times the voltage regulation range in %. In case of a three-phase unit (i.e. in the case of "Star, 3-phase" configuration), the base power is the three-phase one. For all other configurations the base power to be considered is the single-phase one (i.e. the base power of one of the single-phase voltage regulators forming the selected configuration).

The base impedance is always given by:

$$Z_b = \frac{U_n^2}{S_b} \qquad \text{in Ohm} \tag{5}$$

where $S_b$ is calculated as in Section 3.

# 5 Limited Voltage Control Range

According to IEEE C57.15, if the voltage regulation range is limited, the continuous current rating of a voltage regulator can be extended beyond its rated current with a voltage regulation range of $\pm$10% ("Supplementary continuous current rating"). IEEE C57.15 specifies the following continuous current ratings for single-phase and three-phase step-voltage regulators:

Table 5.1: Supplementary continuous current rating in %

| **Range of voltage regulation (%)** | **Single-phase** | **Three-phase** |
|---|---|---|
| 10 | 100 | 100 |
| 8.75 | 110 | 108 |
| 7.5 | 120 | 115 |
| 6.25 | 135 | 120 |
| 5 | 160 | 130 |

Limited control voltage range can be selected in the *Load Flow* page of the element dialog, where separate limits for maximum and minimum taps can be specified. The resulting continuous current rating and the actual minimum and maximum tap positions are automatically shown in the dialog window.

Please note that in case of a thermal rating object (with specified kA or MVA) selected on the element general page, the current rating of the voltage regulator is determined solely based on the specified kA or MVA and source-side bus rated voltage. If the thermal rating is specified in % or if a rating factor is specified, the voltage regulator new current rating is given by the corresponding % of the element continuous current rating (calculated according to Table 5.1).

# 6 Tap Changer

Data for the tap changer can be entered in the type *TypVoltreg*. It is assumed that all single-phase voltage regulators forming the selected three-phase configuration have the same tap changer data. The tap changer is specified by entering the voltage regulation range and the neutral, maximum and minimum tap positions.

In the *Load Flow* page of the element the actual tap positions (e.g. *Tap 1 position*) can be specified for each single-phase voltage regulator forming the selected three-phase configuration. For the ”Star, 3-phase” configuration, the taps are operated together and only one tap position can be specified in the element. For the ”Open delta, 2 x 1-phase” configuration two tap positions can be specified in the element.

## 6.1 Ganged Operation of Taps

In all supported configurations, with the exception of the ”Star 3-phase”, each single-phase voltage regulator is equipped with an independent tap controller. Therefore, the tap positions of each single-phase voltage regulator are independent of each other. By selecting in the element *Load Flow* page the ”gang operated taps” check-box, the taps are operated together. In this case, only one tap position can be specified in the element.

# 7 Automatic Tap Controller

The automatic tap controller can be activated by selecting the *Automatic Tap Changing* in the *Controller* tab of the *Load Flow* page in the element dialog.

For the configuration ”Star, 3-phase” one tap controller simultaneously controls the taps on each phase. For all other configurations, one independent tap controller controls the tap for each single-phase voltage regulator in unbalanced load flow calculations and in unbalanced RMS simulations. In balanced calculations, taps of all single-phase voltage regulators are operated together.

Even though each single-phase voltage regulator is equipped with its independent tap controller, it is assumed that all controllers are equal. Therefore, the entered data about the tap changer type (discrete or continuous), voltage setpoint, controller time constant and line drop compensation will apply to the controller of each single-phase voltage regulator. Hence, it is not possible for example to specify a different voltage setpoint for each single phase voltage regulator (or different line drop compensation parameters).

If the ”gang operated taps” check-box is selected in the element *Load Flow* page, the automatic tap controller can be set to control a phase-to-ground, a line-line or the positive sequence voltage.

For the ”Star, 3-phase” configuration, the automatic tap controller can be set to control a phase-to-ground, a line-line or the positive sequence voltage.

For all other configurations and if the ”gang operated taps” check-box is not selected, the controlled voltage is the one measured by the voltage transformer inbuilt in each single-phase voltage regulator. For the ”Star, 3 x 1-phase” configuration, each single-phase voltage regulator controls a phase-to-neutral voltage on the Load-side. For the ”Closed delta, 3 x 1-phase” and the ”Open delta, 2 x 1-phase” configurations, each single-phase voltage regulator controls a line-line voltage on the Load-side.

For example, in the case of a closed delta, Type A regulator (see Figure 2.3), the single-phase regulator ”3” measures the line-line voltage $V_{ca}$ for Positive phase rotation and the line-line voltage $V_{cb}$ for Negative phase rotation. The same is valid for a Type B regulator. In the case of an open delta, (both for Type A and B) regulator (see Figure 2.5), the single-phase regulator ”2” measures the line-line voltage $V_{cb}$ for ”AB - CB” connection, $V_{bc}$ for ”AC - BC” connection and $V_{ca}$ for ”BA - CA” connection.

Note that in order to have the load flow algorithm adjust the taps while trying to find a solution, in the *Load Flow* command *Basic Options* page, the option *Automatic tap adjustment of transformers* must be enabled.

For further general information on the automatic tap controller, refer also to the 2-Winding Transformer Technical Reference.

## 7.1 Line Drop Compensation

Line drop compensation is used when it is required to control the voltage at a point in the system away from the voltage regulator terminals under varying loading conditions. Hence the line drop compensation models the voltage drop over the line from the voltage regulator terminals to the controlled point. When the line drop compensation is selected, the regulated voltage is no longer the measured voltage at the voltage regulator terminals, but the voltage at a point in the system which is not directly measured.

The required settings for the line drop compensation are the (primary) current transformer rating, the voltage transformer ratio, the resistance *Rset* and the reactance *Xset*. The value of the resistance *Rset* and the reactance *Xset* are entered in Volts. The *Rset* and *Xset* have to reproduce the effect of the actual line resistance and reactance in the line drop compensation circuit. They correspond to the voltage drop in the primary circuit with rated CT current divided by the voltage transformer ratio:

$$R_{set} = \frac{R_{line,Ohm} \cdot \text{Multiplier} \cdot \text{Current transformer rating}}{\text{Voltage transformer ratio}} \quad \text{in V} \tag{6}$$

$$X_{set} = \frac{X_{line,Ohm} \cdot \text{Multiplier} \cdot \text{Current transformer rating}}{\text{Voltage transformer ratio}} \quad \text{in V} \tag{7}$$

where Multiplier is equal to 1 for star connected regulators and equal to $\sqrt{3}$ for delta connected regulators.

### 7.1.1 R-X Internal Compensation

For "Closed delta, 3 x 1-phase" and "Open delta, 2 x 1-phase" configurations the measured voltage on the Load-side is about 30 degrees out of phase with the measured current, assuming a pure resistive load. For the "Open delta, 2 x 1-phase" configuration one single-phase voltage regulator will have the measured current leading the measured voltage and the other single-phase voltage regulator will have the measured current lagging the measured voltage. For the "Closed delta, 3 x 1-phase" configuration the measured current will always lead or lag the measured voltage depending on the connection (Negative phase rotation or Positive phase rotation).

To correct for the phase difference between measured voltages and currents, the values of *Rset* and *Xset* can be adjusted and the adjustment holds for every load power factor [1]. The adjustment can be performed automatically in the model by selecting the corresponding check-box (this requires entering *Rset* and *Xset* as the unadjusted values, according to 6 and 7).

For a lagging unit, the adjusted values for the line drop compensation resistance and reactance are the calculated as [1]:

$$R_{adj} = 0.866 \cdot R_{set} - 0.5 \cdot X_{set} \tag{8}$$
$$X_{adj} = 0.866 \cdot X_{set} + 0.5 \cdot R_{set} \tag{9}$$

For a leading unit, the adjusted values for the line drop compensation resistance and reactance are the calculated as [1]:

$$R_{adj} = 0.866 \cdot R_{set} + 0.5 \cdot X_{set} \tag{10}$$
$$X_{adj} = 0.866 \cdot X_{set} - 0.5 \cdot R_{set} \tag{11}$$

Notice that for a "Closed delta, 3 x 1-phase" configuration it is possible to enter *Rset* and *Xset* directly as the adjusted values without selecting the option for internally adjusting their values. This is not possible for the "Open delta, 2 x 1-phase" configuration, in which case the adjusted *Rset* and *Xset* are different for the two regulators.

### 7.1.2 Voltage Limit

During periods of high load the action of the line drop compensation may cause the local voltage at the voltage regulator Load-side to become too high. To keep the local voltage within safe values, a voltage limit control is used. The function of the voltage limit control is to recognise that the local voltage is high and to limit the contribution of the line drop compensation. Since it is the first houses or customers downward the regulator that would be most affected by a high voltage at the regulator terminals, the voltage limit control is commonly referred to as ”first house protection”. The voltage limit control can be implemented as a physically separate control from the line drop compensation control. In this case the voltage limit control serves as backup control in case of malfunction of the line drop compensation control.

In *PowerFactory* , the voltage limit control is available only when the voltage regulator is operating in the forward direction, i.e. the power flow is from the Source-side to the Load-side.

The voltage limit control can be selected with the *Voltage limit* check-box. If selected, an *Upper* and *Lower* voltage limit and a *Deadband* must be specified. The deadband is applied above the upper limit and below the lower limit.

The way the voltage limit control is implemented is shown in Figure 7.1.

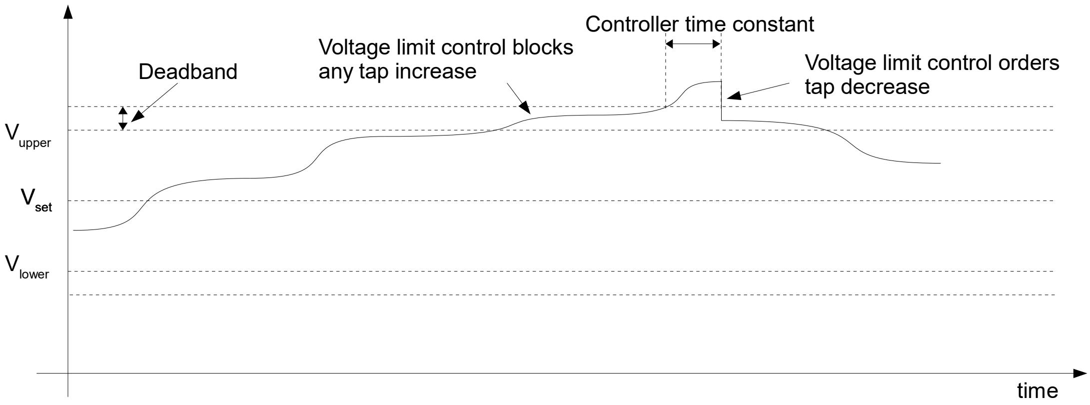



Figure 7.1: Operation of voltage limit control

If the measured Load-side voltage goes above the specified upper limit, the voltage limit control blocks any further rise action required by the line drop compensation control. If the voltage further rises over the deadband, the voltage limit control will require a tap action to decrease the voltage. The tap action will take place after a delay equal to the controller time constant specified for the main controller. This same logic is implemented also for the low voltage case.

## 7.2 Reverse Power Operation

The power flow for a voltage regulator is normally from the Source-side to the Load-side. In particular operating conditions (for example due to other power system components being out of service), a voltage regulator may operate with reverse power flow, i.e. the power flows from the Load-side to the Source-side. If the voltage regulator were to continue to control its Load-side voltage it would run into a maximum (or minimum) tap position, effectively causing too low (or too high) voltage for the loads connected at its Source-side. To avoid this, the voltage regulator has to recognise the reverse power flow and the controlled voltage has to be switched to the Source-side voltage. In other cases, the tap control may just be deactivated during reverse power flow.

In real applications where the Source-side voltage is needed for control, a dedicated voltage transformer may be used or the Source-side voltage may be estimated from the measurement of the Load-side voltage and current.

Each single-phase voltage regulator forming the selected three-phase configuration ("Star, 3 x 1-phase", "Closed delta, 3 x 1-phase" or "Open delta, 2 x 1-phase") has an independent tap controller with dedicated voltage and current transformer. The forward or reverse power operation is determined independently for each single-phase voltage regulator.

When operating in reverse power flow, a new voltage setpoint and new settings for the reverse line drop compensation may be required, depending on the adopted control mode.

*PowerFactory* provides four control modes for reverse power operation:

- Locked Forward
- Bidirectional
- Co-generation
- Q-bidirectional

The power flow direction is determined by the direction of the active component (the reactive component in the Q-bidirectional case) of the measured current as compared to the measured voltage. A *Current deadband (+/-)* can be specified. If the active current magnitude is within the $\pm$ *Current deadband (+/-)*, the controller switches to idle operation. If the active current is negative and its magnitude is higher than the deadband, the controller switches to reverse power operation.

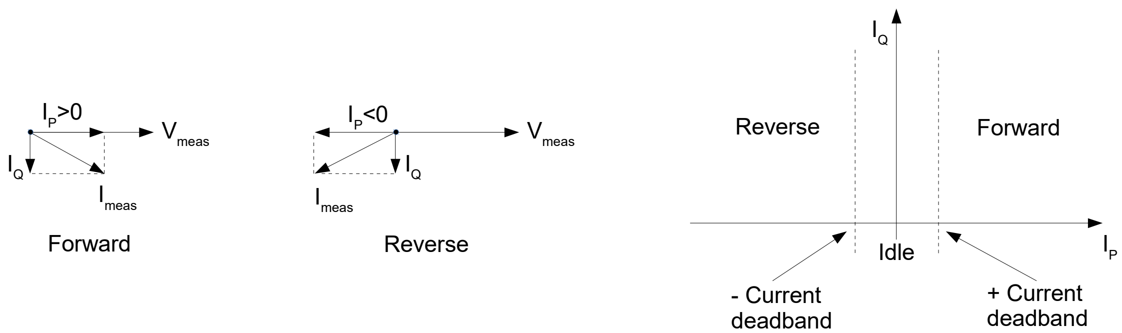



Figure 7.2: Forward, reverse and idle mode of operation

Voltage limit control for reverse power operation is not available in *PowerFactory*.

### 7.2.1 Locked Forward

This control mode allows normal operation of the automatic tap controller for forward power flow, but blocks the controller operation for reverse power flow. The control only needs the Load-side voltage measurement. In both idle and reverse power operation, the tap idles on its last position. If the power flow reverses back to forward direction, the controller will again control the Load-side voltage.

### 7.2.2 Bidirectional

The Source-side voltage needs to be measured in this control mode. When the active current changes to reverse direction, the controller will control the Source-side voltage. New settings for voltage setpoint and line drop compensation to be used during reverse power operation can be defined. The controller time constant is assumed equal to that used during forward operation. If the active current magnitude is lower than the *Current deadband (+/-)*, the tap will idle on its last position.

### 7.2.3 Co-generation

This mode is useful in applications where reverse power flow may occur due to the presence of generation downstream the voltage regulator. The controlled voltage during the reverse power operation remains the Load-side voltage, but with different line drop compensation settings. In this way the regulator can be made to control the voltage near its terminals during reverse power flow conditions. If the active current magnitude is lower than the *Current deadband (+/-)*, the tap will idle on its last position. Notice that from *PowerFactory* 2019, the sign for the reverse line drop compensation settings *Rset* and *Xset*, parameters *ldcrsRev* and *ldcxsRev*, must be negative in order to correctly control the voltage in the forward direction.

### 7.2.4 Q-bidirectional

This control mode is similar the *Bidirectional* mode, but uses the reactive current component to determine the power flow direction. The Source-side voltage needs to be measured in this control mode. When the reactive current changes to reverse direction, the controller will control the Source-side voltage. New settings for voltage setpoint and line drop compensation to be used during reverse power operation can be defined. The controller time constant is assumed equal to that used during forward operation. If the reactive current magnitude is lower than the *Current deadband (+/-)*, the tap will idle on its last position.

# 8 Load Flow

In unbalanced *Load Flow* calculations, the tap positions of each single-phase voltage regulator forming the selected three-phase configuration are independent of each other (except for the ”Star, 3-phase” configuration). In balanced *Load Flow* calculations, the taps of all single-phase voltage regulators forming the selected three-phase configuration are always operated together.

The automatic tap controller is modelled according to section 7. In unbalanced *Load Flow* calculations the tap controllers of each single-phase voltage regulator are operated independently. In balanced *Load Flow* calculations one tap controller controls all the taps.

# 9 RMS Simulation

In unbalanced *RMS* simulations the tap positions of each single-phase voltage regulator forming the selected three-phase configuration are independent of each other (except for the ”Star, 3-phase configuration”). In balanced *RMS* simulations, the taps of all single-phase voltage regulators forming the selected three-phase configuration are always operated together.

The automatic tap controller, modelled according to section 7, is available also in *RMS* simulations if the *Use integrated tap controller* check-box is selected in the *RMS* page of the element dialog. However, in *RMS* simulations only a discrete tap changer is implemented and the continuous tap changer is not supported.

It is also possible to control the taps externally through the input *nntapin1* in balanced *RMS* simulations, and through the inputs *nntapin1*, *nntapin2* and *nntapin3* in unbalanced *RMS* simulations.

# 10 EMT Simulation

In *EMT* simulations the tap positions of each single-phase voltage regulator forming the selected three-phase configurations are independent of each other (except for the ”Star, 3-phase configuration”).

The automatic tap controller is not available in *EMT* simulations.

In *EMT* simulations it is possible to control the taps externally through the inputs *nntapin1*, *nntapin2* and *nntapin3*.

# 11 Harmonics

In the type *TypVoltreg* it is possible to define a frequency characteristics for the resistance and inductance of the series-impedance.

# 12 Input/Output variables of the dynamic model

## 12.1 Stability Model (RMS)

### 12.1.1 Balanced simulations

Table 12.1: Input definition of the RMS-model, balanced

| Input Signal | Symbol | Description | Unit |
|---|---|---|---|
| nntapin1 | | Tap 1 position, controller input | |

### 12.1.2 Unbalanced simulations

Table 12.2: Input definition of the RMS-model, unbalanced

| Input Signal | Symbol | Description | Unit |
|---|---|---|---|
| nntapin1 | | Tap 1 position, controller input | |
| nntapin2 | | Tap 2 position, controller input | |
| nntapin3 | | Tap 3 position, controller input | |

## 12.2 EMT-Model

Table 12.3: Input definition of the EMT-model

| Input Signal | Symbol | Description | Unit |
|---|---|---|---|
| nntapin1 | | Tap 1 position, controller input | |
| nntapin2 | | Tap 2 position, controller input | |
| nntapin3 | | Tap 3 position, controller input | |

# 13 References

[1] Cooper Power Systems Voltage Regulating Apparatus Determination of Regulator Compensator Settings R225-10-1

# List of Figures