EUROPROT +

# Centralized busbar differential and breaker failure protection function

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# Centralized busbar differential and breaker failure protection function

Protecta provides two different types for busbar protection. Both of them perform basically the well-known principle: the sum of the currents flowing into and out of the busbar results zero, if there are no internal faults. If the sum is not zero then there is an internal fault, and a fast trip command is generated. The scheme in both versions is the low impedance, biased differential scheme, the application of Kirchhoff`s node law.

The difference between the two types is the structure of the differential protection system:

- Centralized version:
    - If the number of bays connected to the busbar is limited (there are not more bays than 6) the tasks related to the three-phase busbar differential protection function are performed within one device.
    - With increasing number of the bays the tasks are divided among three independent devices. Each of them is responsible for the differential protection of one phase (L1, L2 or L3) of the busbar. This version can be considered also as a centralized version.
- Decentralized version:
    - In this version other individual protective devices of the bays (e.g. distance protection, overcurrent protection, etc.) are involved in the busbar protection scheme. They are located in the substation according to the bay structure of the primary system. These devices perform the sampling of the currents and have access to all information needed for the busbar protection system. This information is sent by fiber optic link to the central unit. The calculation and decision is performed by the central unit, and the dedicated trip commands are sent back to the devices also via fiber optic links.

This short description contains the details of the centralized version; the decentralized version is described in a separate document.

The numerical protection integrates two independent protection functions:

- numerical differential protection,
- breaker failure protection.

The joint discussion of these functions is based on the fact that the breaker failure protection utilizes the same processed status information of the busbar protection to disconnect only the section of the busbar to which the faulty circuit breaker is connected. So the other zones can remain in continuous service.

The centralized numerical busbar differential protection system has two configuration possibilities:

- It can be realized in one device, processing all three phase currents of all bays if there are not more bays than 6, or
- It can consist of three identical devices processing the phase currents separately for the phases.

This description focuses on the three-phase version, but if needed, the difference as compared to the single phase version is also indicated.

The main features of the busbar differential protection function can be summarized as follows:

- The function is performed within one (or three) device(s), receiving analog currents and voltages and status signals from all bays of the busbar;
- Dynamic busbar replica, based on disconnector status signals;
- High stability in case of external faults in spite of current transformer saturation;
- Short tripping time;
- Selectivity for internal fault, only the bays connected to the faulty busbar section are disconnected, all other bays remain in continuous operation;
- Easily to extend within the limitation of the hardware of three-phase or three single phase hardware versions;
- Easy adaptation of the function for different primary bus systems:
    - Single busbar,
    - Up to quadruple busbar,
    - Ring bus,
    - 1 ½ circuit breaker arrangement,
    - Bus couplers,
    - Bus sectionalizers with none, one or two current transformers,
    - Transfer bus;
- Individual numerical calculation and decision for all three phases;
- Stabilized differential current characteristics;
- The security and stability are increased with special software methods;
- Voltage breakdown condition;
- Check zone application;
- Saturated waveform compensation;
- Directionality check;
- Current transformer failure detection;
- Checking the disconnector status signals;
- Included breaker failure protection.

The capabilities of the busbar differential protection function depend on the hardware configuration. This is a task of the factory process: based on the ordering, the required number of current inputs, binary inputs for disconnector status signals and the required number of trip outputs are assembled into the device.

The applied software functions blocks are as follows:

1. “Busbar” function block: this performs the organization of the busbar protection system, and also the numerical calculations and decisions are performed in this module. Based on the disconnector status information received from the bus sections “Measuring elements” are composed. A “Measuring element” processes all currents, which are flowing into or out of the interconnected bus sections. Accordingly the number of the processed “Measuring elements” can be the number of the individual bus sections, as a maximum; or there can be less “Measuring elements”, if some bus sections are interconnected with each other. The ”Measuring element” performs the algorithm for the interconnected busbar sections. The busbar protection function always contains one “Busbar” function block.

2. “Bus section” function blocks: the number of these blocks coincides with the number of the bus sections. Up to 12 sections can be included. The task of this function block is to process the status signals, and to send them to the “Busbar” block to form the “Measuring elements”.

3. “Bay unit” function blocks: the number of these blocks coincides with the number of the bays in the substation. On the one hand, the task of these block is to receive and process all information from the primary devices of the bay:
    - Currents (three phase currents or one phase current, depending of the selected option)
    - Voltages (three phase voltages or one phase voltage, depending of the selected option)
    - Status signals of the disconnectors: these signals are received with dual signals (disconnector open and diconnector closed). Up to 4 disconnectors can be configured to a physical bay.

   On the other hand, this block passes the trip command to the circuit breaker of the bay.

   This block also inputs the breaker failure signal from the bay protection units, and information related to the “stub” protection. On the other hand, the blocking input signal received by this bay unit disables the operation of the “Measuring element”, to which this bay is dynamically assigned.

4. “Sectionalizer unit” function blocks: these blocks serve mapping the sectionalizer bays, the bays which interconnect bus sections with disconnectors. These blocks receive up to two disconnector status signals.

The algorithm continuously evaluates the status signals of the disconnectors and if there are changes in the status signals then based on the received signals the algorithm performs “configuration”, which means determination of the busbar replica of the substation and an assignment of “Measuring elements” to each interconnected bus sections.

If bus sections are interconnected with each other then only one of the assigned measuring elements performs the calculation and the results are passed to all other inactive measuring elements of interconnected bus sections. Among other things, it means that the on-line displayed values will be the same for these bus sections.

The central unit performs synchronous sampling of all analog signals. These values are used by the assigned “Measuring elements” of the central unit. The “Measuring elements” perform the following tasks:

*The differential current calculation* is as follows:

- Summation of the sampled $I_p$ momentary current values for the bays connected to the “Measuring element”. The result is the calculated momentary value of the differential current:

$$I_{d.p} = \sum I_p$$

- Filtering the current DC component by subtracting the value sampled 10 ms before from the actual value, and the difference is divided by two. The result is the calculated momentary value of the differential current without the DC component.

$$I_{d.p1} = \frac{I_{d.p} - I_{d.p-10ms}}{2}$$

- The magnitudes of the ten last calculated values are averaged, receiving the *Id* trip current. The result is the “rectified average” of the differential current. (The method is the numerical realization of the measuring principle of the Depres measuring instruments).

$$Id = \frac{\sum_{n=1}^{10} \left| I_{d.pn} \right|}{10}$$

*The biasing current calculation* is as follows:

- From the absolute value of the sampled $I_p$ momentary current values, a predetermined "$Max.I\_load$" value, determined with parameter setting is subtracted:

$$\left|I_p\right| - Max.I\_load$$

  Here $Max.I\_load$ is a parameter setting, the proposed value of it is the expected maximum load current value of all bay currents but not higher than the "Base sensitivity" of the differential characteristics. The result is that in normal operation, when all bay currents are below the maximum load current, the calculated values get negative.
- Out of these differences only the values above 0 (if $(\left|I_p\right| - Max.I\_load) > 0$) are summed

$$I_{s.p} = \sum(\left|I_p\right| - Max.I\_load)$$

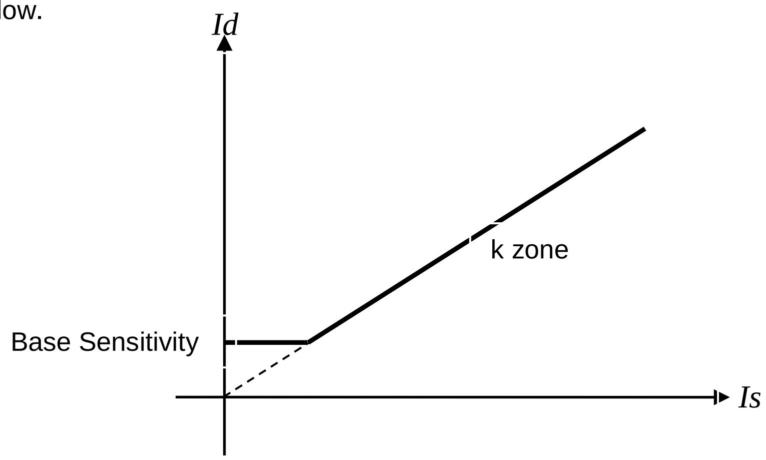
  The sum of these values can be positive only, if there are currents above the maximum load values, i.e. there is a fault (either external or internal of the busbar).
- Then the average of this value and that received 10 ms before is calculated:

$$I_{s.p1} = \frac{I_{s.p} + I_{s.p-10ms}}{2}$$

- The last ten calculated values stored in the memory are averaged, receiving the $Is$ biasing current:

$$Is = \frac{\sum_{n=1}^{10} I_{s.pn}}{10}$$

*The differential characteristics:* the trip characteristic for a measuring element is shown in the Figure below.




In case of detected through fault, the slope of the characteristic is dynamically changed to 90%. When tested, the applied method results a constant 90% measured value for the slope.

*Role of the subtracting the "$Max.I\_load$" value from all current samples*: in normal operation all current samples are expected to be below this setting value, which is to be the maximum possible current peak value. Consequently in normal operation the bias current is zero.

If in this state an internal fault occurs then the current samples get very fast above "$Max.I\_load$" value. Consequently the locus of the Id-Is points on the plane of the differential characteristics (Figure above) is at once above the line described by the slope "k" (parameter setting "k zone"). In this case the trip command needs a few checking points only, the trip command can be fast.

In case of external fault however, the locus of the Id-Is points on the plane of the differential characteristics start moving in the direction of the Is axis. If the algorithm recognizes this movement, i.e. the locus is below the line described by the slope “k” then the number of the required check points gets a high value. This extended checking period does not permit trip command generation during the time period, when the iron core of the overloaded current transformer gets saturated, and it cannot deliver proportional secondary current for the measurement.

*Voltage breakdown condition:* in case of current transformer circuit error, the missing current from any of the bays, the measuring element detects current difference. This could result a trip command to the bus section. To prevent this kind of operation error, the trip command is released only if in the affected bus section the voltage collapses.

To perform this supervision, the presence of the voltage is monitored with a quick voltage measuring function. The result of the supervision is considered in every millisecond. The parameters for the voltage breakdown condition are fix values.

*The check zone:* If any of the status signals received from the bays is wrong then the false operation based on this wrong signal could disconnect the bus section. To avoid this kind of errors the “check zone” is applied. This additional “check zone measuring element” supposes the whole busbar system as a single node. It gets all current samples from the bays except those sampled from the current transformers connecting bus sections and adds them all to get the check zone differential current. The individual measuring elements can generate a trip command only if also the “check zone measuring element” detects an internal busbar fault. The check zone operation must be enabled by parameter setting.

*Saturated waveform compensation:* in case of external fault, with the exception of the faulty bay, all bays deliver currents towards the busbar. The sum of these currents flows through the current transformer of the faulty bay. Consequently this current can be extremely high, which can saturate the iron core of this current transformer. The shape of this secondary current gets distorted, and the “missing” section of the wave-shape is a differential current.

To prevent unwanted operation of the busbar differential protection function for these external faults, there are several remedies. One of them is the “saturated waveform compensation”. The algorithm “keeps” the detected current peak till the end of the half period, decreasing the chanche for the false trip decision.

*Directionality check:* in case of internal fault, all bays deliver currents towards the busbar. In case of external fault however, with the exception of the faulty bay, all bays deliver currents towards the busbar, and the current of the faulty bay flows out of the busbar. When considering this basic difference, the stability of the busbar differential protection can be improved by “directionality check”.

The busbar differential protection algorithm compares the sign of all current samples in a “measuring element”. If during the majority of the samples one of the currents shows opposite sign, indicating opposite direction, then this fact prevents generation of the trip command.

*Current transformer failure detection:* if the current transformers do not deliver correct currents for the evaluation then the correct decision of the busbar differential protection is not possible.

The currents are continuously supervised also during normal operation of the system, when the currents are below the operation level of the differential protection. If in this state any of the currents is missing then a relatively high differential current is measured which is still not sufficient to operate the differential protection. The algorithm performs the current supervision based on a similar characteristic as the trip characteristic, which has a sensitive base setting and a given slope.

If the measured currents result an Id–Is point above this characteristic, then after a time delay the “measuring element” gets blocked.

*Checking the disconnector status signals:* the actual configuration of the busbar is evaluated using status signals of the disconnectors. The status of each disconnectors is characterized by dual signals: “Disconnector open” and “Disconnector closed”. Only one of them can be true and one of them can be false. This function checks these status signals, and performs the decision based on parameter setting.

In normal operation when receiving faulty status signals from the disconnectors the device keeps the previous state for a time period defined by parameter setting. After this time delay the reaction of the algorithm depends on the setting of the dedicated enumerated parameter. If the setting of the “BadState Tolerate” is true (On), then the operation neglects the faulty status signal, and the last valid status is kept. In case of setting “false” (Off), the “measuring element” gets blocked.

If the status error is detected after energizing or following parameter changes, the protection remains disabled until the faulty status is corrected, and generates “Differential protection disabled” and “Breaker failure disabled” status signals as well.

*Measured values:* the measured and displayed values of the centralized busbar differential protection function are listed below.

For each voltage inputs, the device measures and displays the phase voltages. The Table below shows as an example the voltages of a bus section.

| **Measured value** | **Dim.** | **Explanation** |
|---|---|---|
| Voltage Ch - U1 | (secondary) V | Phase voltage L1, Fourier base component |
| Voltage Ch – U2 | (secondary) V | Phase voltage L2, Fourier base component |
| Voltage Ch – U3 | (secondary) V | Phase voltage L3, Fourier base component |

For each bays the device measures and displays the phase currents. The Table below shows as an example the currents of a bay.

| **Measured value** | **Dim.** | **Explanation** |
|---|---|---|
| Current Ch - I1 | (secondary) A | Phase current L1, Fourier base component |
| Angle Ch - I1 | deg* | Phase angle of the current in L1 |
| Current Ch – I2 | (secondary) A | Phase current L2, Fourier base component |
| Angle Ch – I2 | deg* | Phase angle of the current in L2 |
| Current Ch – I3 | (secondary) A | Phase current L3, Fourier base component |
| Angle Ch – I3 | deg* | Phase angle of the current in L3 |

For each bus sections the device measures and displays the differential currents and the bias currents. The Table below shows as an example the currents of a bus section.

| **Measured value** | **Dim.** | **Explanation** |
|---|---|---|
| I Diff L1 | (primary) A | Differential current L1, Fourier base component |
| I Diff L2 | (primary) A | Differential current L2, Fourier base component |
| I Diff L3 | (primary) A | Differential current L3, Fourier base component |
| I Bias L1 | (primary) A | Bias current L1, Fourier base component |
| I Bias L2 | (primary) A | Bias current L2, Fourier base component |
| I Bias L3 | (primary) A | Bias current L3, Fourier base component |

*<u>The breaker failure protection function:</u>*

The starting of the breaker failure protection is received on dedicated binary input channels. For operation, at least one of the phase currents of the bay must be above the level, as set an integer parameter value for each bay. Also the time delay of the function and the duration of the pulse are parameter values.

Based on the status signals of the disconnectors, the algorithm selects all bays, which are interconnected with the bay announcing breaker failure. Accordingly only the minimum number of the bays gets the trip command, the other bus-sections remain in continuous operation.

*In the total description of the function, some additional features and useful advices are described in details in the Appendices.*

## Technical data

| Function | Value | Accuracy |
|---|---|---|
| Current measurement | | ±2% |
| Current reset ratio | 0.7* | |
| Operate time<br>(Idiff>2 x In)<br>(Idiff>5 x In) | <br>Typical 20 ms<br><15 ms | |
| Reset time | 60 ms | |

** The reset ratio is the result of the applied special algorithm*

# ***<u>The parameters of the centralized busbar differential protection function</u>***

## Parameters of the central unit

### Enumerated parameters

| Parameter name | Title | Selection range | Default |
|---|---|---|---|
| Parameter to enable the centralized busbar differential protection function: | | | |
| Busbar_BBPOper_EPar__ | Operation | Off, On | Off |
| Parameter to enable the supervision by the “check zone” | | | |
| Busbar_CheckOper_EPar_ | CheckZone Operation | Off, On | Off |
| Toleration of the disconnector status signal errors | | | |
| Busbar_BadTol_EPar_ | BadState Tolerate | Off, On | Off |

### Integer parameter

| Parameter name | Title | Unit | Min | Max | Step | Default |
|---|---|---|---|---|---|---|
| Percentage characteristic, base sensitivity | | | | | | |
| Busbar_ZoneSens_IPar_ | Base Sensitivity | A | 100 | 10000 | 1 | 1000 |
| Percentage characteristic, slope | | | | | | |
| Busbar_ZoneK_IPar_ | k zone | % | 40 | 90 | 1 | 80 |
| Checkzone percentage characteristic, base sensitivity | | | | | | |
| Busbar_CheckSens_IPar_ | CheckZone Sens. | A | 100 | 10000 | 1 | 1000 |
| Checkzone percentage characteristic, slope | | | | | | |
| Busbar_CheckK_IPar_ | k checkzone | % | 40 | 80 | 1 | 50 |
| CT error detection, base sensitivity | | | | | | |
| Busbar_CTErrSens_IPar_ | CT failure Sens. | A | 50 | 5000 | 1 | 500 |
| CT error detection, slope | | | | | | |
| Busbar_CTErrK_IPar_ | k CT failure | % | 40 | 80 | 1 | 40 |
| Maximum load current | | | | | | |
| Busbar_Offset_IPar_ | Max.I_load | A | 0 | 10000 | 1 | 1000 |

### Timer parameters

| Parameter name | Title | Unit | Min | Max | Step | Default |
|---|---|---|---|---|---|---|
| Time delay for signaling bad state | | | | | | |
| Busbar_BadDelay_TPar_ | BadState Delay | msec | 100 | 60000 | 1 | 1000 |
| Time delay for signaling CT error | | | | | | |
| Busbar_CTErrDelay_TPar_ | CT failure Delay | msec | 100 | 60000 | 1 | 1000 |

## Parameters of the bus section unit

The bus section units do not need parameter setting.

## Parameters of the bay unit

### Boolean parameters

| Parameter name | Title | Default | Explanation |
|---|---|---|---|
| Disabling the bay | | | |
| BayUnit1f_BayDisable_BPar__T1 | Bay Disable | 0 | 0 means enabling;<br>1 means that the current values and the status signals received from the bay are not considered (to be applied for maintenance purposes). |

### Enumerated parameters

| Parameter name | Title | Selection range | Default |
|---|---|---|---|
| CT secondary rated current | | | |
| BayUnit1f_Nom_EPar__T1 | Rated Secondary | 1A, 5A | 1A |
| Location of the CT star point for the CT-s in three lines | | | |
| BayUnit1f_Dir_EPar__T1 | Star point I1-3 | Line, Bus | Line |

NOTE: If the bay does not include a current transformer then these parameters are missing.

### Integer parameter

| Parameter name | Title | Unit | Min | Max | Step | Default |
|---|---|---|---|---|---|---|
| CT primary rated current | | | | | | |
| BayUnit1f_CTNom_IPar__T1 | CT nominal | A | 100 | 10000 | 1 | 1000 |

NOTE: If the bay does not include a current transformer then this parameter is missing.

## Parameters of the sectionalizer unit

The sectionalizer units do not need parameter setting.

# ***Parameters of the breaker failure unit***

## Parameters of the central unit

### Enumerated parameters

| Parameter name | Title | Selection range | Default |
|---|---|---|---|
| Parameter to enable the trip command distribution of the breaker failure protection function | | | |
| Busbar_BFPOper_EPar_ | Intertrip Operation | Off, On | Off |

## Parameters of the bay unit

### Enumerated parameters

| Parameter name | Title | Selection range | Default |
|---|---|---|---|
| Enabling the bay to participate in the protection function | | | |
| BRF50BB_Oper_EPar__B1 | Operation | Off,On | Off |

### Integer parameter

| Parameter name | Title | Unit | Min | Max | Step | Default |
|---|---|---|---|---|---|---|
| Current condition for the breaker failure protection function | | | | | | |
| BRF50BB_StCurrPh_IPar__B1 | Start Ph Current | % | 20 | 200 | 1 | 30 |

### Timer parameters

| Parameter name | Title | Unit | Min | Max | Step | Default |
|---|---|---|---|---|---|---|
| BRF50BB_BUDel_TPar__B1 | Backup Time Delay | msec | 60 | 1000 | 1 | 200 |
| BRF50BB_Pulse_TPar__B1 | Pulse Duration | msec | 0 | 60000 | 1 | 100 |

## *Binary output status signals of the centralized busbar differential protection module*

The conditions of the binary input signals are defined by the user applying the graphic equation editor.

### Binary output status signals of the central unit

| Binary output signals | Signal title | Explanation |
|---|---|---|
| Busbar_Blocked_GrI_ | Blocked | The busbar protection is in blocked state |
| Busbar_DCError_GrI_ | DC Error | Disconnector status error |

### Binary output status signals of the bus section unit

| Binary output signals | Signal title | Explanation |
|---|---|---|
| | | |
| BusSec_TripL1_GrI__M01* | Trip L1* | L1 trip signal for the bus section |
| BusSec_TripL2_GrI__M01* | Trip L2* | L2 trip signal for the bus section |
| BusSec_TripL3_GrI__M01* | Trip L3* | L3 trip signal for the bus section |
| BusSec_Trip_GrI__M01 | Trip | General trip command for the bus section |
| BusSec_BFPTrip_GrI__M01 | BFP Trip | Trip command generated by the breaker failure protection function |
| BusSec_CTError_GrI__M01 | CT Error | Error in current measurement |
| BusSec_Ublock_GrI__M01 | U block | The differential protection is blocked by voltage condition |

** Valid in three-pole version only*

### Binary output status signals of the bay unit

| Binary output signals | Signal title | Explanation |
|---|---|---|
| BayUnit1f_DCErr_GrI__T1 | DC Error | Disconnector error |
| BayUnit1f_Trip_GrI__T1 | Trip | Trip command to the circuit breaker of the bay |
| BayUnit_BayDisable_GrI__B1U | Bay disabled | Bay disabled |

### Binary output status signals of the sectionalizer unit

| Binary output signals | Signal title | Explanation |
|---|---|---|
| SecStat_StatErr_GrI__K | Status Error | Status signal error |
| SecStat_SectClosed_GrI__K | Sect. Closed | Closed state of the sectionalizer |

## *Binary output status signals of the breaker failure module*

| Binary output signal | Signal title | Explanation |
|---|---|---|
| BRF50BB_BuTr_GrI__B1 | Backup Trip | Trip command for the bay, generated by the breaker failure function |

## ***Binary input status signals of the centralized busbar differential protection module***

The conditions of the binary input signals are defined by the user applying the graphic equation editor.

### Binary input status signals of the central unit

| Binary input signals | Signal title | Explanation |
|---|---|---|
| Busbar_BBPBlock_GrO_ | BBP Block | Blocking the busbar differential protection function |
| Busbar_BFPBlock_GrO_ | BFP Block | Blocking the breaker failure protection function |

### Binary input status signals of the bus section unit

The bus section units do not have binary input status signals

### Binary input status signals of the bay unit

| Binary input signals | Signal title | Explanation |
|---|---|---|
| BayUnit_BFPTrip_GrO_ | BFP Trip | Breaker failure signal from the protection of the bay. The breaker failure protection passes this signal to all bays of the interconnected bus sections, related to this particular bay |
| BayUnit_DC1Close_GrO_ | DC1 Close | Disconnector 1 in closed state |
| BayUnit_DC1Open_GrO_ | DC1 Open | Disconnector 1 in open state |
| BayUnit_DC2Close_GrO_ | DC2 Close | Disconnector 2 in closed state |
| BayUnit_DC2Open_GrO_ | DC2 Open | Disconnector 2 in open state |
| BayUnit_DC3Close_GrO_ | DC3 Close | Disconnector 3 in closed state |
| BayUnit_DC3Open_GrO_ | DC3 Open | Disconnector 3 in open state |
| BayUnit_DC4Close_GrO_ | DC4 Close | Disconnector 4 in closed state |
| BayUnit_DC4Open_GrO_ | DC4 Open | Disconnector 4 in open state |
| BayUnit_ForceZero_GrO_* | Force Zero* | In TRUE state of this input signal the bay unit sends zero value as the sampled current |
| BayUnit_BlkSect_GrO_ | Blk Sect | In TRUE state of this input signal the measuring element related to this bay gets in blocked state |

** NOTE: In bay units without CT this parameter is missing*

### Binary input status signals of the sectionalizer unit

| Binary input signals | Signal title | Explanation |
|---|---|---|
| SecStat_DC1Close_GrO_ | DC1 Close | Disconnector 1 in closed state |
| SecStat_DC1Open_GrO_ | DC1 Open | Disconnector 1 in open state |
| SecStat_DC2Close_GrO_ | DC2 Close | Disconnector 2 in closed state |
| SecStat_DC2Open_GrO_ | DC2 Open | Disconnector 2 in open state |

## ***Binary input status signals of the breaker failure module***

| Binary input signals | Signal title | Explanation |
|---|---|---|
| BRF50BB_Blk_GrO_1 | Block | Blocking the breaker failure protection |
| BRF50BB_GenSt_GrO_1 | General Start | Starting the breaker failure protection |