

**Contents**

<b>1. Introduction .....</b>	<b>3</b>
1.1 Features.....	3
1.2 Application .....	3
<b>2. Description.....</b>	<b>4</b>
2.1 Function block symbol .....	4
2.2 Input description .....	5
2.3 Output description.....	6
<b>3. Description of operation.....</b>	<b>7</b>
3.1 Configuration .....	7
3.1.1 Analog channels .....	7
3.1.2 Tap changer position inputs .....	8
3.1.3 Manual command inputs.....	10
3.1.4 Follower operation .....	13
3.1.5 Operation Mode inputs .....	14
3.1.6 Network connection status input.....	15
3.1.7 External block input .....	15
3.1.8 Tap changer operating (TCO) input.....	16
3.1.9 Reduce Set Voltage (RSV) input .....	16
3.1.10 Communication inputs / outputs .....	17
3.1.11 BLOCK_STATUS Output.....	18
3.1.12 Alarm output .....	18
3.2 Voltage regulator operation principle .....	19
3.2.1 Voltage control vs. tap changer moving direction .....	20
3.2.2 Operate timer functionality.....	21
3.3 Regulation equation.....	22
3.4 Line Drop Compensation (LDC).....	23
3.4.1 LDC equation and parallel connection.....	25
3.5 Parallel Operation .....	25
3.5.1 General .....	25
3.5.2 Master/Follower (M/F) mode.....	26
3.5.3 Minimizing Circulating Current (MCC) mode .....	30

3.5.4	Negative Reactance Principle (NRP) .....	33
3.5.5	Comparison Summary.....	35
3.6	Blockings .....	37
3.6.1	Overcurrent .....	38
3.6.2	Undervoltage .....	38
3.6.3	Overvoltage .....	38
3.6.4	High Circulating Current .....	39
3.6.5	BLOCK – Function Block Input.....	39
3.6.6	Extreme Positions .....	39
3.7	Fast Lower Control .....	40
3.8	Tap Changer Monitoring.....	40
3.8.1	Command error .....	41
3.8.2	TCO signal does not fall .....	41
3.8.3	Regulator pumping .....	41
<b>4.</b>	<b>Parameters and events.....</b>	<b>43</b>
4.1	General.....	43
4.2	Setting values .....	44
4.2.1	Actual Settings .....	44
4.2.2	Setting Group 1 .....	44
4.2.3	Setting Group 2 .....	45
4.2.4	Control Settings.....	46
4.3	Measurement values .....	47
4.3.1	Input Data.....	47
4.3.2	Output Data .....	48
4.3.3	Event Codes.....	49
<b>5.</b>	<b>Technical data .....</b>	<b>50</b>

# **1. Introduction**

## **1.1 Features**

- Automatic or manual voltage control of power transformers using raise and lower signals to the on load tap changer
- Parallel operation of transformers, by the Master/Follower (M/F), Negative Reactance Principle (NRP) or Minimizing Circulating Current (MCC) principle
- Supervision of several blocking conditions
- Line drop compensation (LDC) included
- Load shedding based on voltage reduction
- Persistent for network fault conditions
- Automatic adaptation of operation based on the switching status at a substation
- Definite time characteristic or inverse time characteristic for delays between raise and lower operations
- Several methods supported for tap changer position value transfer

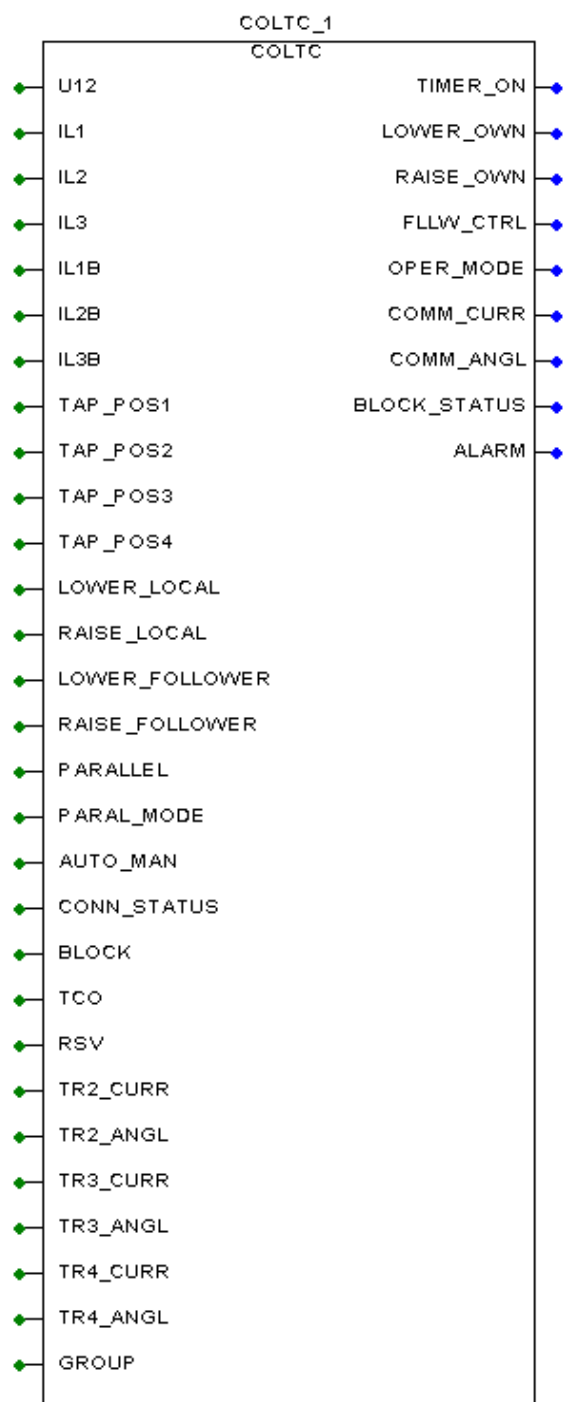
## **1.2 Application**

This document describes the function of the voltage regulator function block, COLTC, used in products based on the RED 500 Platform.

The voltage regulator COLTC is designed to be used for regulating the voltage of power transformers with on load tap changers in distribution substations.

## 2. Description

### 2.1 Function block symbol



## 2.2 Input description

Name	Type	Description
U12	Analogue Signal Channel (SINT)	Channel measuring the phase-to-phase voltage Uxy on the regulated side
IL1	Analog Signal Channel (SINT)	Channel measuring phase current IL1 (HV side)
IL2	Analog Signal Channel (SINT)	Channel measuring phase current IL2 (HV side)
IL3	Analog Signal Channel (SINT)	Channel measuring phase current IL3 (HV side)
IL1B	Analog Signal Channel (SINT)	Channel measuring phase current IL1 LV side)
IL2B	Analog Signal Channel (SINT)	Channel measuring phase current IL2 (LV side)
IL3B	Analog Signal Channel (SINT)	Channel measuring phase current IL3 (LV side)
TAP_POS1	SINT	Integer value representing tap changer position for transformer 1 (own transformer)
TAP_POS2	SINT	Integer value representing tap changer position for transformer 2
TAP_POS3	SINT	Integer value representing tap changer position for transformer 3
TAP_POS4	SINT	Integer value representing tap changer position for transformer 4
LOWER_LOCAL	BOOL, pos. edge	Lower command input from HMI
RAISE_LOCAL	BOOL, pos. edge	Raise command input from HMI
LOWER_FOLLOWER	BOOL, pos. edge	Lower command input from master (Master/Follower operation mode)
RAISE_FOLLOWER	BOOL, pos. edge	Raise command input from master (Master/Follower operation mode)
PARALLEL	BOOL	Parallel (TRUE) or single (FALSE) operation
PARAL_MODE	USINT	Input for changing the operation in parallel mode via logic
AUTO_MAN	BOOL	Selection between manual (TRUE) / automatic (FALSE) in single mode or master (TRUE) / follower (FALSE) in parallel mode
CONN_STATUS	BOOL, active high	Network connection status of the (own) transformer
BLOCK	BOOL, active high	External signal for blocking of automatic operation
TCO	BOOL, active high	Tap changer operating input
RSV	UINT	Reduce set voltage multiplier
TR2_CURR	UINT	Current IL1b + 1 bit for supervision (msb) via horizontal communication from transformer 2
TR2_ANGL	UINT	Packed angle between U1 and IL1b + additional info via horizontal communication from transformer 2

Name	Type	Description
TR3_CURR	UINT	Current IL1b + 1 bit for supervision (msb) via horizontal communication from transformer 3
TR3_ANGL	UINT	Packed angle between U1 and IL1b + additional info via horizontal communication from transformer 3
TR4_CURR	UINT	Current IL1b + 1 bit for supervision (msb) via horizontal communication from transformer 4
TR4_ANGL	UINT	Packed angle between U1 and IL1b + additional info via horizontal communication from transformer 4
GROUP	BOOL	Control input for switching between setting group 1 and setting group 2. When GROUP is TRUE (logic 1), group 2 is active. Otherwise. group 1 is active.

### 2.3 Output description

Name	Type	Description
TIMER_ON	BOOL, active high	Timer T1, T2 or fast lower timer is active
LOWER_OWN	BOOL, active high	Lower command pulse for own transformer
RAISE_OWN	BOOL, active high	Raise command pulse for own transformer
FLLW_CTRL	BYTE	Lower and raise command pulses for follower transformers in the Master/Follower operation mode (bit-coded output)
OPER_MODE	USINT	The operation mode of the function block
COMM_CURR	UINT	Measured IL1b amplitude + 1 bit for supervision (msb) to be sent via horizontal communication
COMM_ANGL	UINT	Packed measured angle between U1 and IL1b + additional information to be sent via horizontal communication
BLOCK_STATUS	BYTE	Bit-coded output showing the blocking status for the next operation
ALARM	BOOL, active high	Alarm state of COLTC

## 3. Description of operation

### 3.1 Configuration

The measuring devices and signal types for the analog channels are selected and configured in a special dialogue box of the Relay Configuration Tool. The digital inputs are configured in the same programming environment (the number of selectable analog inputs, digital inputs and digital outputs depends on the hardware used).

#### 3.1.1 Analog channels

The measured voltage must be a phase-to-phase voltage from the regulated side. Typically, this is the phase-to-phase voltage U12b from the low voltage (LV) side of the power transformer. However it is possible to use any other phase-to-phase voltage (signal types U23b, U31b, U12, U23 or U31) or virtual phase-to-phase voltage measurement, for example a signal type U12bs, if the phase-to-phase measurement is not available. The voltage can be measured with a conventional voltage transformer.

The phase currents can be measured with conventional current transformers. If certain signal types are not present, the corresponding inputs are left unconnected, and COLTC adapts its operation based on the connected inputs.

COLTC uses the phase currents IL1 – IL3 from the high voltage (HV) side for overcurrent blocking. The highest phase current value is used in the evaluation. This maximum value is shown in the output data “Primary current”. One, two or all phase current inputs can be left unconnected. If all phase current inputs from the primary side are missing, a current from the secondary side is used for overcurrent blocking evaluation. Correspondingly, this maximum value is always shown in the output data “Second. current”.

The phase currents from the secondary side of the power transformer (IL1b - IL3b) are used for the following purposes:

- Overcurrent blocking if all primary side currents are missing (maximum of the connected inputs).
- Line drop compensation (average of the connected inputs).
- Calculating circulating current in the operation modes: Negative Reactance Principle (NRP) and Minimizing Circulating Current (MCC). Note that the lowest connected input, and *not* any average, is used for calculations. In here, the term lowest connected means the lowest phase number, i.e., if all phases 1, 2 and 3 are connected, the lowest connected is phase 1. If only phases 2 and 3 are connected, the lowest connected is phase 2 etc.

One, two or all phase current inputs can be left unconnected. If all the phase current inputs from secondary side are missing, the operation features mentioned above are not in use.

### 3.1.1.1

#### The analog signals of the regulator

Both voltage U12b and the phase currents at the LV side (IL\_b) are always measured using the RMS value of the filtered fundamental frequency component. Hence, the harmonics are always suppressed. Moreover, the measured voltage value is continuously average filtered so that the *sliding* window length = 8 (task intervals). As told above, the numerically calculated voltage U1 is always used in calculations, although it is not connected. Furthermore, if the voltage U12\_ or the current IL\_b is not connected and other phases are, an internal phase compensation takes care that the calculations are done based on the numerically compensated signals U12\_ or IL1\_. This value, the parameter  $U_m$  in Eq. 1, is used for control, and its magnitude can be read from the input data "Voltage U12".

Similarly, the magnitude of the phase current of the own transformer, IL\_b and the phase angle difference between voltage U1 and phase current IL\_b (note that this angle difference is used both in Eq. 6 and Eq. 8) are also average filtered by the same length *fixed* window. This phase angle value can be read from the input data "Angle U1-IL1". These currents and phase angle differences are used solely on circulating current calculations, and the communication outputs (see chapter Communication inputs / outputs) are updated in intervals of 500 ms.

There are minimum limits for the voltage and current magnitudes, resulting in that the magnitude and phase angle difference values diverge from zero. The voltage magnitude must exceed 3% of  $U_n$  and the current IL\_b must exceed 2% of  $I_n$ .

The phase currents from the primary side of the power transformer are used solely for overcurrent blocking purposes. Therefore the peak calculation principle is applied to measure these values. The result is not filtered and the instantaneous peak value is used for blocking. Peak and not peak-to-peak measurement is selected here, because the DC-component in the current is to be taken into account. If the primary side signals are not connected, the RMS-values of the secondary side signals are used for overcurrent blocking.

### 3.1.2

#### Tap changer position inputs

The position value of the tap changer can be brought to COLTC as a resistance value, a mA signal or as a binary coded signal.

For more information on how the resistance value or the mA signal interface is implemented, refer to the Technical Reference Manual of the relay. For the binary coded interface via the function blocks BCD2INT, GRAY2INT and



NAT2INT, refer to the Generic Base Elements function block manual (1MRS752371-MUM).

If the position value is brought to COLTC as a mA or a resistance signal, a special Transducer Linearization Tool should be used to define what a particular mA or resistance level stands for. The RTD inputs can then be connected to COLTC via conversion blocks in the IEC 61131-3 tool. The next figure shows an example of how this can be done.

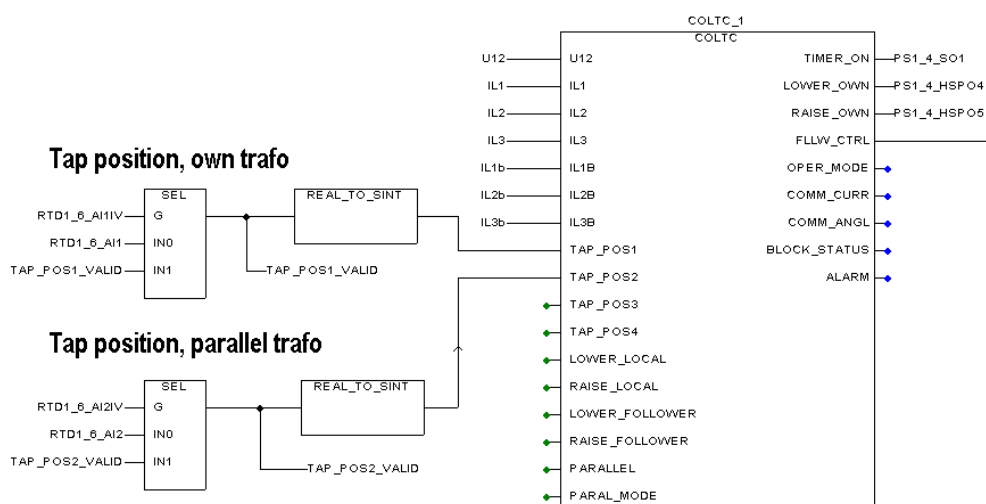


Figure 1. An example configuration, where mA signals is brought from the own transformer (master) and from the parallel transformer (follower) in the Master/Follower operation mode.

The logic for tap position transmission, as seen in Figure 1, ensures that the last valid value is used. As indicated in Figure 1, the tap changer position of the own transformer is to be connected to the TAP\_POS1 input and the tap changer positions of the parallel transformers to the other TAP\_POSx inputs. This also defines the connection identity so that follower 2 is connected to TAP\_POS2, follower 3 is connected to TAP\_POS3 and follower 4 is connected to TAP\_POS4, respectively. These tap changer positions can be read from input data “Input TAP\_POSx”, where x is a value between 1 and 4. The value 99 for an input indicates that there is no tap changer position connected.

A tap changer position change in the own transformer generates an event, 144E29, “TC position value change” and the data field of this event includes the value TAP\_POS1.

Yet another method to deliver tap changer position information to COLTC is to use horizontal communication. It must be remembered that the transferred information is of UINT type, implying a positive integer value. Because the tap changer position is signed integer in the range  $-36 \dots 36$ , at least the maximum value (+36) must be added to the tap position value on the transmitter side and, vice versa, subtracted from the same value on the receiver side. Special attention should be paid to the type conversions in the configuration sheet so

that the value types incremented or decremented are the correct ones. When these are correct, also the ADD or SUB calculation block outputs are of the correct type. For example, if the tap changer position of the own transformer is  $-23$ , then the value  $(-23+36=) 13$  is delivered via the horizontal communication. As a result, at the receiver side, the tap changer position value is decoded back to  $-23$ . The REAL\_TO\_SINT type conversion implements rounding but no cutting, so no problems in value transfer will occur.

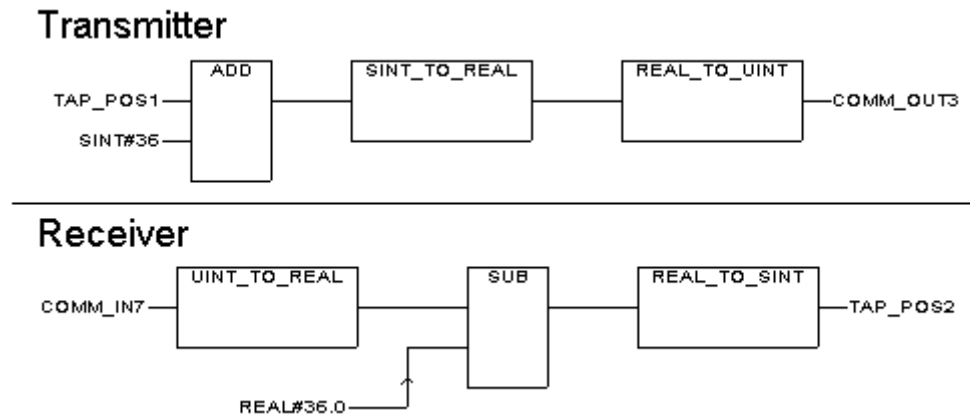


Figure 2. Type conversions when the tap changer position is delivered via horizontal communication.

### 3.1.3

#### Manual command inputs

Manual raise and lower commands can be given either via the HMI of the relay, via remote commands or via the binary inputs of an external function block (CODC\_, CO3DC\_ and COCB\_). The use of CO3DC\_ is recommended, as the other types are usually needed for other purposes. Figure 3 and Figure 4 below show examples where the CO3DC1 function block is used for manual controlling of the tap changer. The RAISE\_LOCAL and LOWER\_LOCAL inputs of the COLTC are used for manual commands as seen in Figure 3.

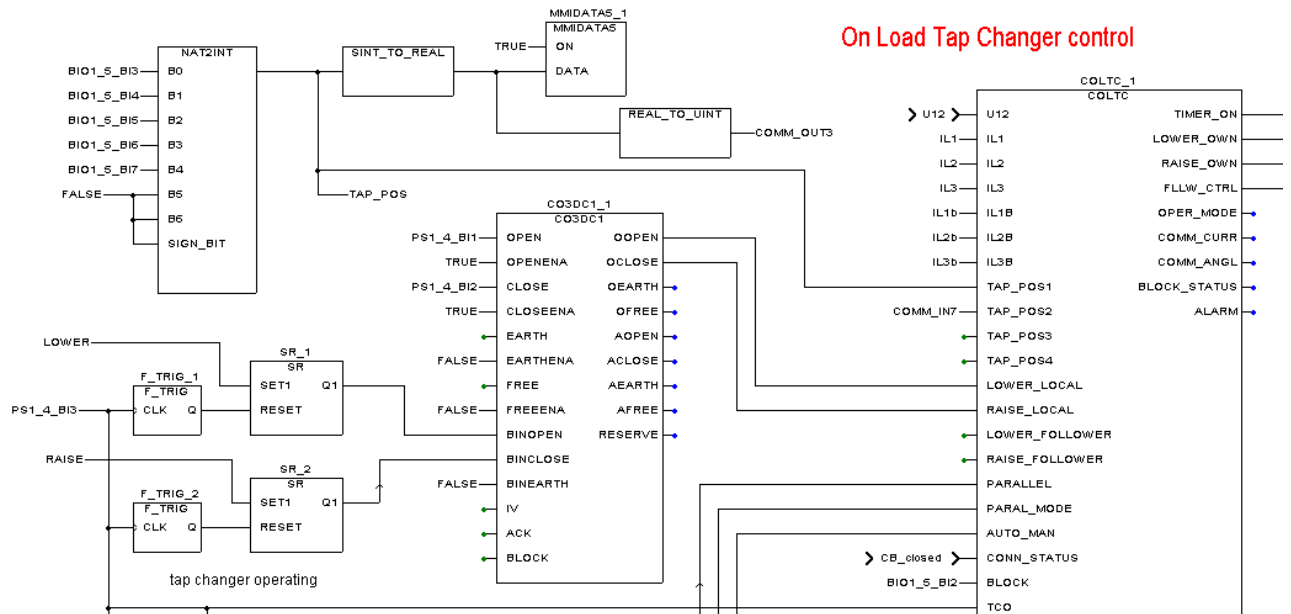


Figure 3. An example configuration where CO3DC1 is used for passing the manual commands to COLTC.

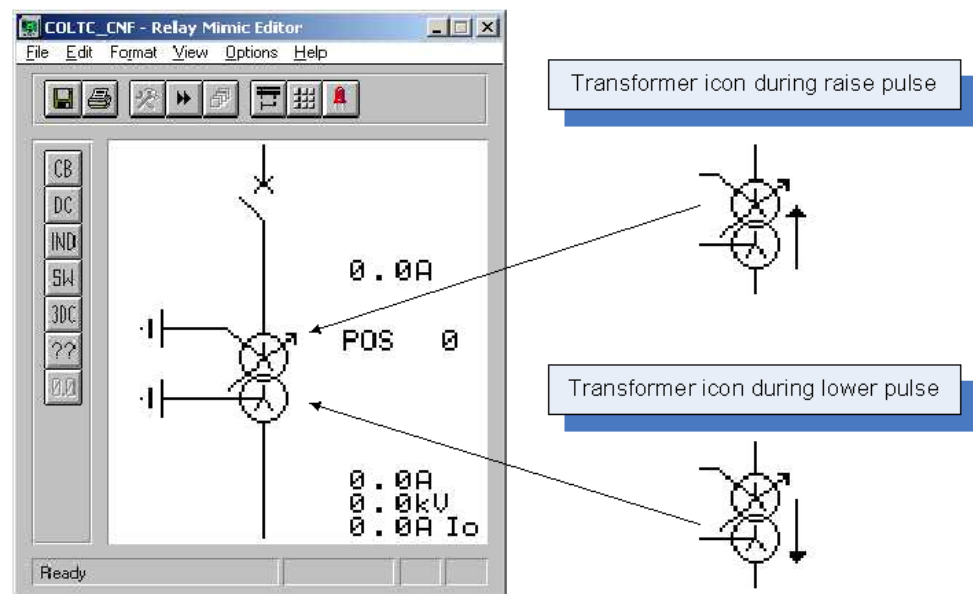


Figure 4. Example on the COLTC (CO3DC\_) HMI-symbols.

After the configurations with Relay Configuration Tool and Relay Mimic Editor, the COLTC symbol (which is actually the symbol of the CO3DC\_) can be selected on the HMI. Now raise commands with the I-button and lower commands with the O-button can be given.

It is notable that the CO3DC\_ function block was originally designed for controlling a three state disconnector. CO3DC\_ provides HMI indications for control actions such as selection, control and supervision of the object under control. These indication texts do not fully comply with the actual control

actions directed at the on load tap changer. The interpretation of the indications is described in the following text.

Note that the operation mode of the COLTC must be set to "Manual" in order to execute the control commands manually. An accepted manual raise/lower command activates the corresponding RAISE\_OWN/LOWER\_OWN output, which is used to control the voltage of the own transformer.

After selecting the transformer icon (the CO3DC\_ symbol representing the COLTC) for control, the indication text is usually "CO3DC\_ Undefined state". This is due to the fact that the initial state of the CO3DC\_ is "00" unless either the RAISE or the LOWER control signal is active at the moment of selection (see Figure 3 for a configuration example). This implies that either the raise or the lower command can be given. After a successful raise or lower command, the event 139/140E10 is given at the next task cycle after the COLTC output pulse activation.

If the local HMI command is interlocked by CO3DC\_ (OPENENA/CLOSEENA = FALSE), the interlocked LED is lit. If the local HMI command is blocked by the BLOCK-input, the indication "CO3DC\_ Blocked" follows after the transformer icon is selected in the HMI. If a command is given, the interlocked LED is lit and the event 139/140E24 is given for command. If the CO3DC\_ IV-input is active (=TRUE), and the transformer icon is selected in the HMI, the indication "CO3DC\_ Invalid state" follows. However, the commands after this are successful.

If the OPEN or CLOSE inputs of CO3DC\_ are activated, then an unsuccessful command due to OPENENA/CLOSEENA = FALSE gives the event 139/140E28 and the interlocked LED is lit.

An active BLOCK or IV input of CO3DC\_ does not inhibit commands given via binary inputs. However, the event 139/140E10 is not given.

A remote command for CO3DC\_ gives either a successful operation, with event 139/140E10 or an unsuccessful operation (due to OPENENA/CLOSEENA = FALSE or active CO3DC\_ BLOCK), with event 139/140E24.

It is strongly recommended that the default settings of CO3DC\_ are changed in order to suppress unnecessary events during manual raise and lower commands and to avoid unnecessary alarms. The following changes are sufficient:

- "Open alarm": 10 s => 0 s
- "Close alarm": 10 s => 0 s
- "Event mask 1A" to "285213696", "Event mask 1B" to "0" (allows CO3DC\_ events E10, E24 and E28)

Please refer to the CO3DC\_ function block manual (1MRS752347-MUM) for more detailed description.

### 3.1.4

### Follower operation

There are two inputs that are used for follower operation. The operation mode of the COLTC must be set to “Autom. follower” in order to execute the follower control commands. There are two inputs that are used for follower operation. The two signals, LOWER\_FOLLOWER and RAISE\_FOLLOWER, are extracted from the FLLW\_CTRL output of the master controller, as seen in Figure 5.

The FLLW\_CTRL output is used in the Master/Follower operation mode to transfer commands from the master controller to the followers. Only one of the parallel controllers can be defined as master simultaneously. It is up to the user to avoid the existence of more than one master controller. Besides one master, the other parallel controllers are defined to be followers. If desired, a logic that controls the M/F activity for the parallel transformers can be used (see section Master/Follower (M/F) ). Table 1 below illustrates what different output values mean as commands. Note that FLLW\_CTRL can be read as a real bit vector type.

*Table 1. The bit-coded FLLW\_CTRL –output and the meaning of the different bits.*

Bit	5(msb)	4	3	2	1	0(lsb)
Command	raise follower 4	lower follower 4	raise follower 3	lower follower 3	raise follower 2	lower follower 2

The reason, why the commands for the control of the followers is combined into one output, is that in this way, the output value can be directly connected to the LON communication output. Consequently, one to many –connection – from the master to the followers can be built with only one LON communication output variable.

However, it is still possible to connect the master and the followers without communication as discrete wiring. Then the FLLW\_CTRL –output can be unpacked like presented in the next figure or, alternatively, using the BITGET function. The status of the FLLW\_CTRL output can be checked via the “Output FLLW\_CTRL” output data.

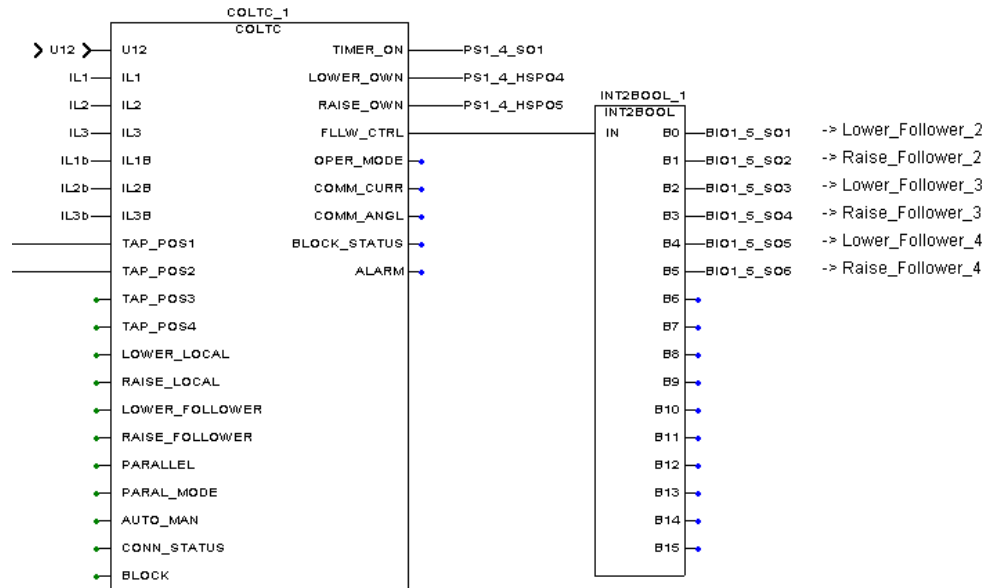


Figure 5. Unpacking of the bit-coded output FLLW\_CTRL for discrete wiring.

### 3.1.5

#### Operation Mode inputs

COLTC has a setting, “Operation mode” for selecting the desired operation mode. It can have any of the following values: “Not in use”, “Manual”, “Autom. single”, “Autom. master”, “Autom. follower”, “NRP”, “MCC” and “Op.mode inputs”. If the last one is selected, the operation mode is determined by the COLTC inputs PARALLEL, PARAL\_MODE and AUTO\_MAN, as depicted in Table 2.

The PARALLEL input defines if the transformer (voltage regulator) is in parallel or single mode. AUTO\_MAN defines the operation status in single mode. It is also used to determine if the voltage regulator acts as a master or a follower in Automatic Master/Follower mode. PARAL\_MODE defines the parallel operation principle. Switching between parallel operation mode and automatic single mode, for instance, can be based on the busbar circuit breaker (CB) status by connecting the CB status information of the PARALLEL input.

Every change in operation mode generates the event 144E27, “Operation mode of COLTC”. The data field of this event includes a new operation mode value that also can be read from the output data “Output OPER\_MODE” or from the OPER\_MODE output. Furthermore, a 3 second start delay occurs, causing for example on-going timer reset. This start delay also occurs during relay boot. However, an operation mode change does not cease an on-going output pulse.

Table 2. Operation mode determined by the operation mode inputs.

PARAL_MODE	AUTO_MAN	PARALLEL	Operation Mode
0 or 1 or 2	0	0	Manual
0	0	1	Automatic follower
0 or 1 or 2	1	0	Automatic single
0	1	1	Automatic master
1	0 or 1	1	MCC
2	0 or 1	1	NRP

### 3.1.5.1

#### Command Exclusion

An operation mode change using three inputs is needed when the operation mode must be changed automatically, i.e. there is a logic, which drives the three operation mode inputs based on the status information from the circuit breakers (see e.g. Figure 12).

It is advised that the CO3DC\_ function block is used to transfer manual commands to COLTC as explained earlier, in the chapter Manual command inputs. In this way the common Local/Remote (L/R) exclusion concerns the manual raise and lower commands of the COLTC. I.e. it internally provides the exclusion mechanism to prevent remote commands (from SCADA) when the relay is in local mode and vice versa.

### 3.1.6

#### Network connection status input

The separate input CONN\_STATUS tells if the corresponding transformer is connected to the network (=TRUE) or not (=FALSE). This input is used to identify if a certain transformer controller is able to send the current information to other transformer controllers for circulating current minimization purposes. As a result, this input has effect only in the “MCC” or “Manual” operation modes. In these modes, if CONN\_STATUS is TRUE, the information transmission is started. On the other hand, circulating current information receiving is allowed only in the “MCC” operation mode when CONN\_STATUS is TRUE.

### 3.1.7

#### External block input

The external BLOCK input can be used to avoid automatic control pulses being activated. Note that timer operation in automatic modes is not disabled if this input is activated. Timer on/off events are sent, but the final pulse itself is never issued. Also note, that in “Manual” operation mode, external BLOCK input has no effect at all. The status of the BLOCK input can be read from the “Input BLOCK” input data.

### 3.1.8 Tap changer operating (TCO) input

The tap changer generates an operating signal that is active when the tap changing process is active. This signal is to be connected to the TCO input. The signal is used for alarming purposes. If the signal is active (=TRUE) for more than 15 seconds *after the control pulse has been deactivated*, an alarm is generated (for more information, see section Tap Changer Monitoring). Note that if the TCO-input is not connected, no alarm is generated.

*Control operation is not disabled while the TCO signal is active.* Thus, it is possible for the controller to send new pulses to the tap changer even when it is already operating. This can be claimed to be unwise, because tap changers are typically immune to new pulses while they are operating. Furthermore, although the pulses are omitted, the tap changer pulse counter of the controller is incremented.

On the other hand, commands are not tolerated during active pulse. This is the reason why command pulse length (setting "Output pulse") has to be carefully selected, because active input TCO is not internally used for preventing new commands to the tap changer.

If the user does not want any new pulses to be sent while the tap changer is in operation, the "Tap changer operating" signal must be connected to the BLOCK input as well. In this case, external blocking is achieved when an automatic pulse is sent to the operating tap changer. External BLOCK has no effect when the operation mode is set to "Manual".

The status of the TCO input can be read from the "Input TCO" input data.

### 3.1.9 Reduce Set Voltage (RSV) input

When the active power production in the network is smaller than its consumption, the system frequency decreases. Either the power supply has to be increased or some loads have to be shed in order to restore the power balance.

The simplest way to decrease the load is to reduce the voltage level by giving a lower reference voltage value to the regulators. For this purpose COLTC has the parameter "RSV step". Setting an integer value to the RSV input activates the reduction. If this input is set to "1", a set target voltage value is decreased by 1 x "RSV step". Correspondingly, if the input value is set to "2", a reduction of 2 x "RSV step" is obtained, etc. The decreased value is kept as a target value as long as a non-zero value is present in the RSV input.

Because the decrease of frequency indicates a need to reduce the load, it is practical to connect the start signal of an underfrequency function block to the integer input mentioned above. Figure 6 shows an example on how the configuration can be made by using Freq\_St\_ function blocks. Note that the figure is only schematic since the COLTC and Freq1St\_ function blocks are executed in different tasks in the configuration.



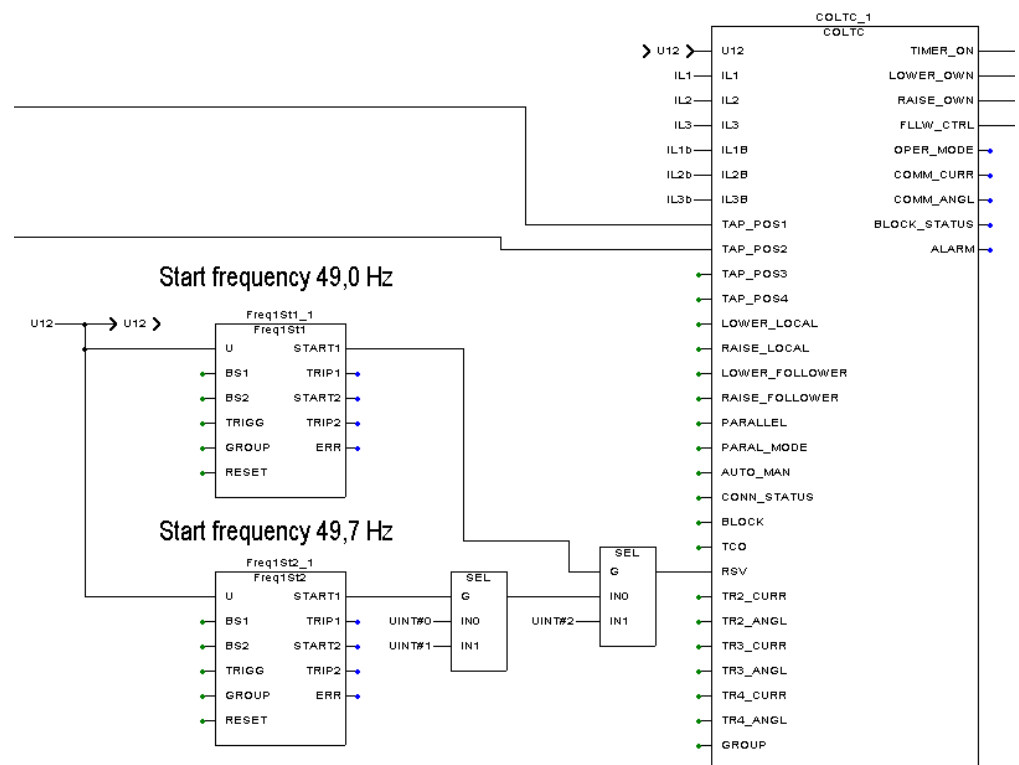


Figure 6. Two step reference voltage reduction when system frequency is decreased.

It is important to notice that it depends on the load characteristics, how much the load is reduced as the voltage drops. For instance, purely resistive loads are proportional to the square of the voltage, whereas motor drives based on frequency controllers may draw constant power despite small voltage changes.

A change in the RSV input generates the event 144E7 “RSV input change”, which is not involved in the default event mask. However, note that setting a change in “RSV step” does not generate any event. The status of the RSV input can be read from the “Input RSV” input data.

### 3.1.10

## Communication inputs / outputs

The communication inputs TRx\_CURR and TRx\_ANGL and their corresponding outputs COMM\_CURR and COMM\_ANGL are needed only in the MCC operation mode. These inputs and outputs are used to transfer the measured current amplitude and the phase angle value between relays. The LNT tool is used to build a horizontal LON communication between relays. For more information, see section Minimizing Circulating Current.

### 3.1.11 BLOCK\_STATUS Output

The BLOCK\_STATUS output is also packed. The type of BLOCK\_STATUS is BYTE. It can be read as a real bit vector type. It contains information about the blocking status as bit-coded output. The BLOCK\_STATUS output does not indicate the actual blocking but indicates if the coming command will be successful or not. The actual blocking is indicated via sent blocking events (E8...E17, E25) or/and studying the corresponding output data ("Block OverCurr", "Block UnderVolt", "Block OverVolt", "Block ExtBlock", "Block Circ.curr") values.

Table 3 below illustrates the meaning of different output values.

*Table 3. The bit-coded BLOCK\_STATUS –output and the meaning of the different bits.*

Bit	6(msb)	5	4	3	2	1	0 (lsb)
<b>Blocking reason</b>	Lowest position reached	Highest position reached	External BLOCK	High circ. Current	Over-voltage	Under-voltage	Over-current

If the status of the certain blocking reason is needed in the IEC 61131-3 configuration, the INT2BOOL function block (see Table 3) or the BITGET function can be used to unpack the information to individual bits.

### 3.1.12 Alarm output

For alarm output, please refer to the chapter Tap Changer Monitoring.

### 3.2

### Voltage regulator operation principle

The voltage regulator function block (COLTC) is intended for control of power transformers with a motor driven on load tap changer. The function is designed to regulate the voltage at the secondary side of the power transformer. The control method is based on a step-by-step principle, which means that a control pulse, one at a time, is issued to the tap changer mechanism in order to move it exactly one position upwards or downwards.

The purpose of the regulator is to maintain a stable secondary voltage of the power transformer. The basis for this operation is the reference voltage, which is set by the user. By adding or decreasing various compensation factors, the regulator calculates a control voltage from the reference voltage (see Eq. 3). Hence, the control voltage is the desired transformer secondary voltage to be maintained by the regulator. Then the control voltage is compared with the voltage measured and the difference between these two forms the regulating process error.

Since the tap changer changes the voltage in steps, a certain error has to be allowed. This error, called bandwidth, (see  $\Delta U_s$  in Figure 7), is also set by the user. A recommended setting for the bandwidth ( $\Delta U_s$ ) should be close to the step voltage of the transformer and never under 50% of it as a minimum. If the measured voltage fluctuates within the control voltage  $\pm$  the bandwidth, the regulator is inactive. Should, on the other hand, the measured voltage be outside these bandwidth limits, an adjustable delay T1 starts (see Figure 7), where the lower-function has been taken as an example). The delay T1 remains active as long as the measured voltage is outside the hysteresis limits of the bandwidth. The factory setting for the hysteresis is 20% of the set bandwidth.

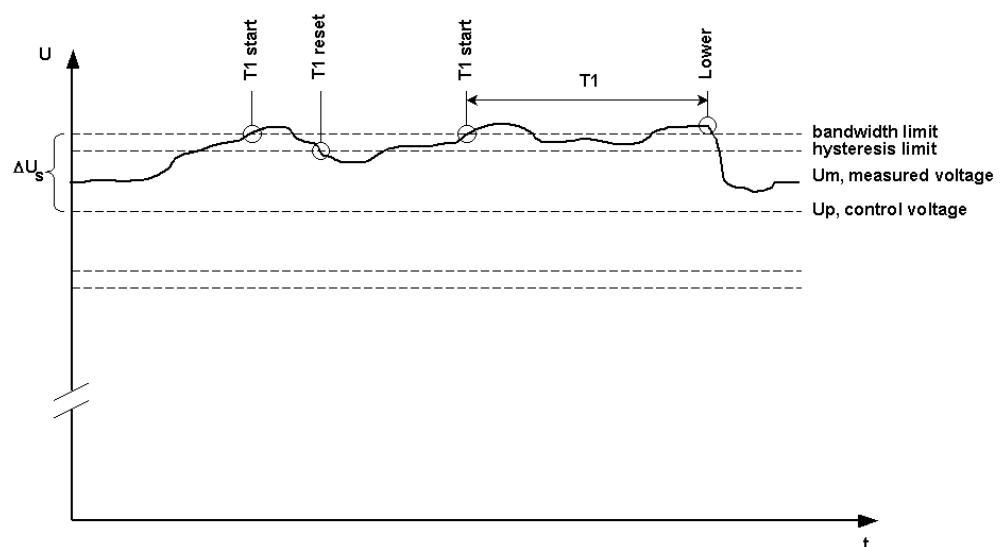


Figure 7. Voltage regulating function. A control pulse to lower the voltage is issued after  $T1$ .

Should the measured voltage still be outside the hysteresis when the delay counter T1 reaches its setting value, the raise or lower output relay is activated, causing the activation of either output pulse RAISE\_OWN or LOWER\_OWN and the motor drive of the tap changer operates. The status of these outputs can be read from the output data “Output RAISE\_OWN” or “Output LOWER\_OWN”, respectively. Furthermore, the event 144E3 “Voltage raise output signal/Activated” or 144E5 “Voltage lower output signal/Activated” is sent. These events are not involved in the default event mask.

If the measured voltage, on the other hand, falls/rises within the hysteresis limits during operating time, the delay counter is reset.

After pulse deactivation, the corresponding reset event 144E2 “Voltage raise output signal/Reset” or 144E4 “Voltage lower output signal/Reset” is sent. The pulse length can be defined using the “Output pulse” control setting, where the default value is 1.5 seconds.

A short delay, defined to be the same as the typical tap changer operating time, is active before the start of the next operating timer is possible. For COLTC this delay is set to 6 seconds. If one tap changer operation is not enough to regulate the transformer voltage within the hysteresis limits, a second adjustable delay T2, usually with a shorter time setting than T1, starts. This delay is used for the following control commands within the same sequence until the recovery of voltage occurs. The delays T1 and T2 can be selected either with definite or inverse time characteristics. In the inverse time mode operation, the operate time depends on the difference between the control voltage and the measured voltage (see Eq. 1). The bigger the difference in voltage is, the shorter is the operate time. The inverse time operation is described more in detail in chapter Operate timer functionality.

### 3.2.1

#### Voltage control vs. tap changer moving direction

The COLTC has the control settings “Min.Volt.Tap” and “Max.volt.tap.”. Setting “Min.volt.tap.” and “Max.volt.tap.” should give the tap changer position that results in *the lowest and highest controlled voltage value* (usually at the LV side of the transformer). The setting of both “Max.volt.tap.” > “Min.volt.tap.” and “Min.volt.tap.” > “Max.volt.tap.” is allowed.

In the first case, “Max.volt.tap.” > “Min.volt.tap.”. In this case, raise control activates the RAISE\_OWN output. This will result in that the tap changer *raises* its position by one step and the measured voltage rises. Furthermore, the event 144E3 “Voltage raise output signal/Activated” is sent and in the output data we can see “Output RAISE\_OWN/Active”. If TAP\_POS1 is connected, then the event 144E21, “Tap changer alarm”, is sent if tap changer does not move *upwards* by exactly one step in 20 seconds after the pulse activation, the “Alarm reason” in the output data is “001”.

Lower control (see Figure 7) works in a similar way. The event 144E5 “Voltage lower output signal/Activated” is sent and in the output data we can see “Output LOWER\_OWN/Active”. Now an alarm is generated if the tap changer

does not move *downwards* by exactly one step in 20 seconds after the pulse activation (assuming that TAP\_POS1 is connected).

In the second case, the parameters are set so that “Min.volt.tap.” > “Max.volt.tap.”. Raise control activates the RAISE\_OWN output. The result should be that the tap changer *lowers* its position by one step and the measured voltage rises. Furthermore, the event 144E3 “Voltage raise output signal/Activated” is sent and we can see “Output RAISE\_OWN/Active” in the output data. If TAP\_POS1 is connected, then the event 144E21, “Tap changer alarm” is sent if the tap changer does not move *downwards* exactly by one step in 20 seconds after the pulse activation, the “Alarm reason” in the output data is “001”.

Lower control (see Figure 7) works in a similar way. The event 144E5 “Voltage lower output signal/Activated” is sent and in the output data we can see “Output LOWER\_OWN/Active”. Now an alarm is generated if the tap changer does not move *upwards* by exactly one step in 20 seconds after the pulse activation (assuming that TAP\_POS1 is connected)

### 3.2.2

#### Operate timer functionality

- |    |              |  |
|----|--------------|--|
| T1 | Delay time 1 | The first delay, when the measured voltage exceeds or falls below the limit value.                     |
| T2 | Delay time 2 | The second delay, when the first control action did not bring the measured voltage to a desired level. |

The delay times can be set to follow either the definite time characteristic or the inverse time characteristic with the control setting “Delay mode”. By default, the definite time type operation has been selected. The timer mode cannot be changed between cycles T1 and T2, but only either before T1 has started or after T2 has elapsed. The action delay after the command pulse activation and the restart of the timer is 6 seconds, assumed to be the tap changer operating delay. Timer start and elapse generate the events 144E1 “Operation timer/Activated” and 144E0 “Operation timer/Reset”, respectively. However, these events are not involved in the default mask. The timer status can also be read from the output data “Output TIMER\_ON”.

#### 3.2.2.1

#### IDMT Type Operation

The IDMT timer can be selected by setting “Delay mode” = “Inverse time”. The minimum time at inverse time characteristic is limited to 1.0 s. However, the minimum recommended setting of the delay times T1 and T2 is 10 s when definite time delay is used, and 25 s when inverse time delay is used.

The inverse time function is defined by the following equations:

$$B = \frac{U_d}{\Delta U_s} \quad \text{Eq. 1}$$

Where:  $U_d = |U_m - U_p|$ , differential voltage  
 $\Delta U_s$  = setting parameter "Bandwidth"

$$t = \frac{T}{2^{(B-1)}} \quad \text{Eq. 2}$$

Where:  $T = T1 \text{ or } T2$

The output data "dU" shows the differential voltage value  $U_m - U_p$ . If the value exceeds the "Bandwidth" setting and has a negative sign, then a raise pulse is going to be issued. The "dU" output data can also be seen in the DT timer mode.

The hysteresis approach has already been dealt with in Figure 7 earlier.

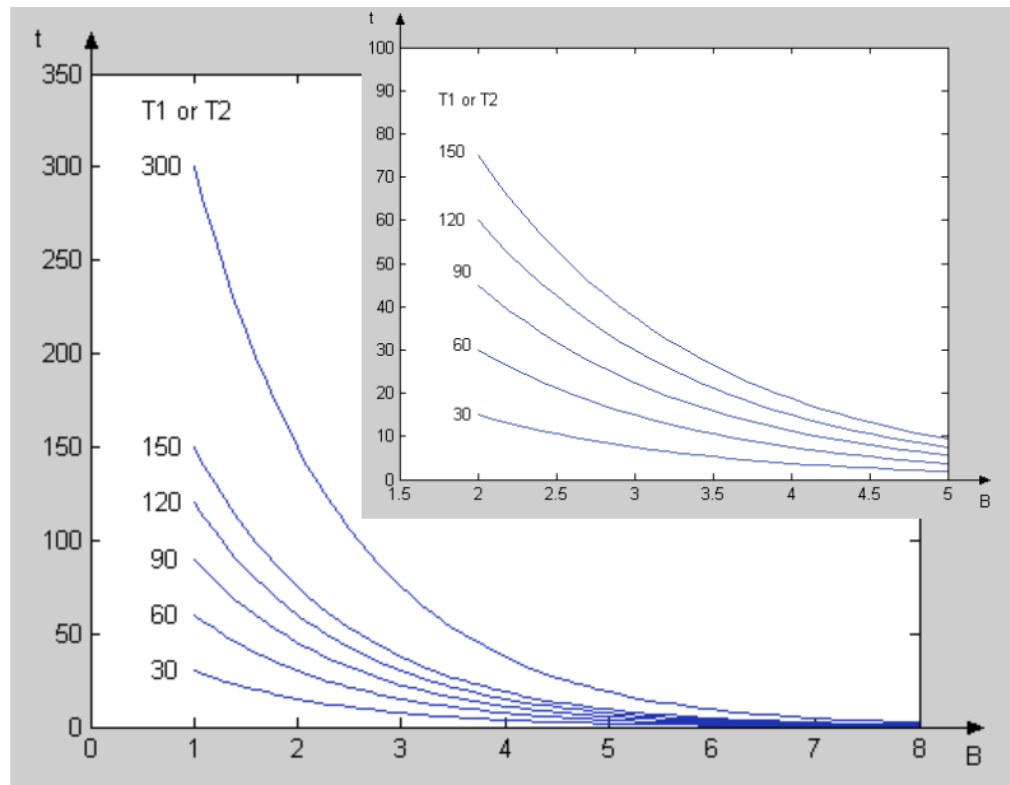


Figure 8. Inverse time characteristic for different values on T1 or T2. (The smaller figure is a zoom of the larger one.)

### 3.3

#### Regulation equation

The simple regulating principle described in the chapter Voltage regulator operation principle is often complemented by additional features to take the voltage drop of lines into account (line drop compensation) and to coordinate the regulation of parallel transformers and to change the voltage level

according to the loading state of the network. The control voltage  $U_p$  is therefore calculated according to the following formula:

$$U_p = U_s + U_z + U_{ci} - U_{rsv} \quad \text{Eq. 3}$$

in which:

$U_s$  = the set voltage level (setting “Reference voltage”)

$U_z$  = the line-drop compensation term

$U_{ci}$  = the circulating current compensation term

$U_{rsv}$  = the voltage reduction parameter

The meaning of the terms and parameters is explained more in detail in the following sections.  $U_p$  can be directly read in the output data “Control voltage”.

The circulating current compensation term is calculated only in the parallel operation modes NRP and MCC, which are described more in detail later in the section Parallel Operation.

### 3.4

#### Line Drop Compensation (LDC)

The line drop compensation feature is used to compensate the voltage drop along a line or network fed by the transformer. The compensation setting parameters can be calculated theoretically, if the resistance and reactance of the line are known, or practically, by measuring the line drop.

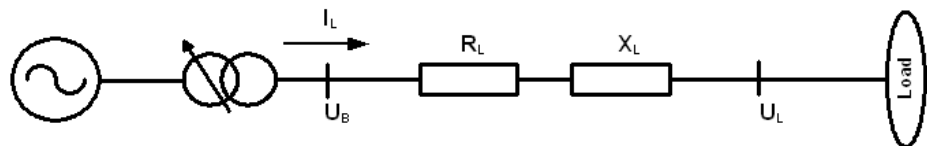


Figure 9. Equivalent electrical circuit for calculating the LDC term.

The compensation parameters to be given,  $U_r$  and  $U_x$ , are percentage values of  $U_n$  according to the following expressions.

$$U_r[\%] = \frac{\sqrt{3} \times I_n \times R}{U_n} \times 100 \quad \text{Eq. 4}$$

$$U_x[\%] = \frac{\sqrt{3} \times I_n \times X}{U_n} \times 100$$

Where:

$I_n$  = rated current of the power transformer

$U_n$  = rated main voltage of the power transformer

$R$  = resistance of the line,  $\Omega$ /phase

$X$  = reactance of the line,  $\Omega$ /phase

By default, line drop compensation (LDC) is not active. LDC is activated by setting the “LDC selection” parameter to “ON”. In order to keep the LDC term within acceptable limits in all situations, COLTC has a setting parameter, “LDC limit”, which has a default value of 10 % (from  $U_n$ ). As a result, this gives the maximum value for  $U_z$  in Eq. 3.

If more than one line is connected to the LV busbar, the equivalent impedance should be calculated and given as a parameter setting (see Figure 9). For instance, if there are N number of identical lines with identical loads in the substation, the R- and X-values needed for the settings  $U_r[\%]$  and  $U_x[\%]$  are obtained by dividing the resistance and the reactance of one line by N. Because the voltage drop is different in lines with different impedances and load currents, it is necessary to make a compromise when setting the  $U_r[\%]$  and  $U_x[\%]$  parameters. Raising the voltage in the point of lowest voltage must not lead to overvoltage elsewhere.

The line drop compensation is effective on the normal active power flow direction only. If the active power flow in the transformer turns opposite (i.e. from the regulated side towards the system in the upper level), the LDC term is ignored, i.e. set to zero. In such a case it is assumed that the feeding units at the regulated side of the transformer(s) should maintain proper voltage levels. This may cause a conflict, if the transformer tries to reduce the voltage at the substation. In addition to this, it is difficult to predict the actual voltage levels in the feeder lines in such a case, and lowering the voltage at the substation may have harmful effects in the far end of the network.

Naturally, topology changes in the network may cause changes to the equivalent impedance value of the network. If the change is substantial, the setting groups can be used to switch between different setting values for  $U_r[\%]$  and  $U_x[\%]$ . In practice this means that the Boolean type information from the topology change is connected to the GROUP input of COLTC.



### 3.4.1

### LDC equation and parallel connection

The additional challenge in the parallel connection regarding line drop compensation is to know the total current which flows through the parallel transformers. The general LDC equation is given in Eq. 5.

$$U_z = I_{injected} \left( \frac{U_r[\%] + jU_x[\%]}{100} \right) \quad \text{Eq. 5}$$

In the Master/Follower mode this is a bit easier than in other parallel modes, since the transformers are assumed to have identical ratings, i.e. the total current ( $I_{injected}$  in Eq. 5) is obtained by multiplying the measured load current (the average of the secondary currents IL1b, IL2b and IL3b of the connected own transformer) with the number of parallel transformers. COLTC can internally conclude the number of parallel transformers from the connected tap changer position inputs. On the contrary, if there is not any position information from the other parallel transformers connected, the correct number of the parallel transformers, excluding the own transformer, needs to be set with the parameter “Parallel trafos”.

In the MCC mode, the horizontal communication transfers the information from the measured load currents between the regulators, so that the total current needed in the line drop compensation can be summed up accurately. Here  $I_{injected}$  is defined to be the phasor sum of all the transformers' (both own and parallel) lowest connected secondary side currents (IL1b or IL2b or IL3b). The currents from the other transformers must be fed via the TRx\_CURR and TRx\_ANGL inputs.

In the NRP mode, the parallel transformers have different ratings and there is no communication between the regulators. Therefore, when setting  $U_r[\%]$  and  $U_x[\%]$ , the  $I_n$  used in the formula should be the sum of the rated currents of all the transformers operating in parallel. Here  $I_{injected}$  is also defined to be the average of the connected secondary currents (IL1b, IL2b and IL3b). The calculated line drop compensation value can be read from the output data “LDC”.

## 3.5

## Parallel Operation

### 3.5.1

### General

It is likely that a circulating current between transformers will occur if two or more transformers with slightly different ratios are energized in parallel. This is due to unbalanced short circuit impedances of the parallel transformers. In order to avoid such currents, the tap changers of the transformers should be adjusted to achieve equilibrium. If the transformers are assumed identical, the tap (voltage) steps and tap positions should also match. If this is the case, the

Master/Follower principle can be used. However, also unequally rated transformers with different tap steps can be connected in parallel and these configurations can also be managed by the tap changer control function. For these configurations, the Minimizing Circulating Current principle or the Negative Reactance Principle should be used. These principles (MCC and NRP) are suitable for identical transformers as well.

The circulating current (which is almost purely inductive) is defined as negative if it flows towards the transformer. Then  $U_{ci}$  in Eq. 3 is positive and the control voltage  $U_p$  rises as a result to the "Voltage raise output signal" being activated if the circulating current level is sufficient enough (see Eq. 7 or Eq. 9). The other parameters remain the same. The result should then be that the voltage rise diminishes the circulating current.

### 3.5.2 Master/Follower (M/F) mode

The Master/Follower operation mode is suitable for power transformers with identical ratings and step voltages. One voltage regulator (master) measures and controls, and the other regulators (followers) follow the master, i.e. all the tap changers connected in parallel are synchronized. This parallel operation is obtained by connecting the unpacked FLLW\_CTRL output of the master to the corresponding inputs of the followers (see Figure 5). If several regulators are to act as masters (one at a time), their outputs also have to be routed to the inputs of the other regulators. To start parallel operation, the master regulator is set to "Autom. master" -mode, and the followers to "Autom. follower" mode.

In order to keep all the tap changers in the same position, the master needs to know the tap positions of the followers. In this way the circulating current is kept at its minimum. The position values of the followers can be brought to the master either via horizontal LON communication, or by wiring mA or resistance signals from the follower transformers.

The status information from circuit breakers and extra logic can be used to change the operation mode via inputs of the master and the follower. Figure 10, Figure 11 and Figure 12 show a configuration example in such a case.

## 3.5.2.1

## M/F configuration example

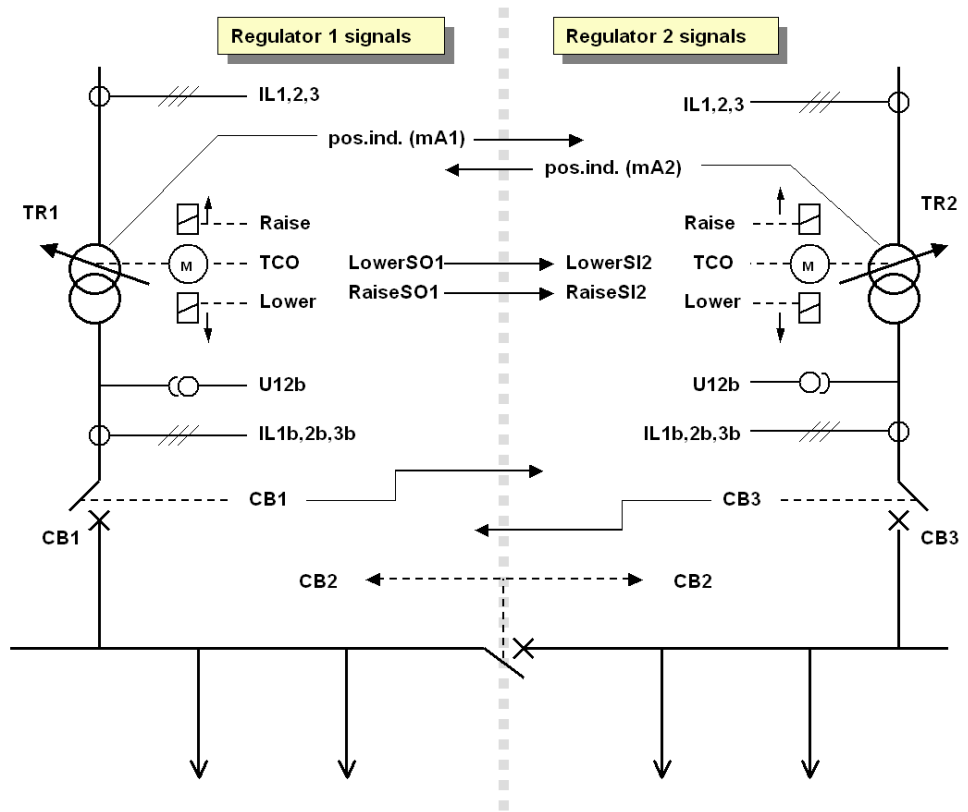


Figure 10. An example of the configuration for the automatic Master/Follower operation mode (the position of the follower known by the master).

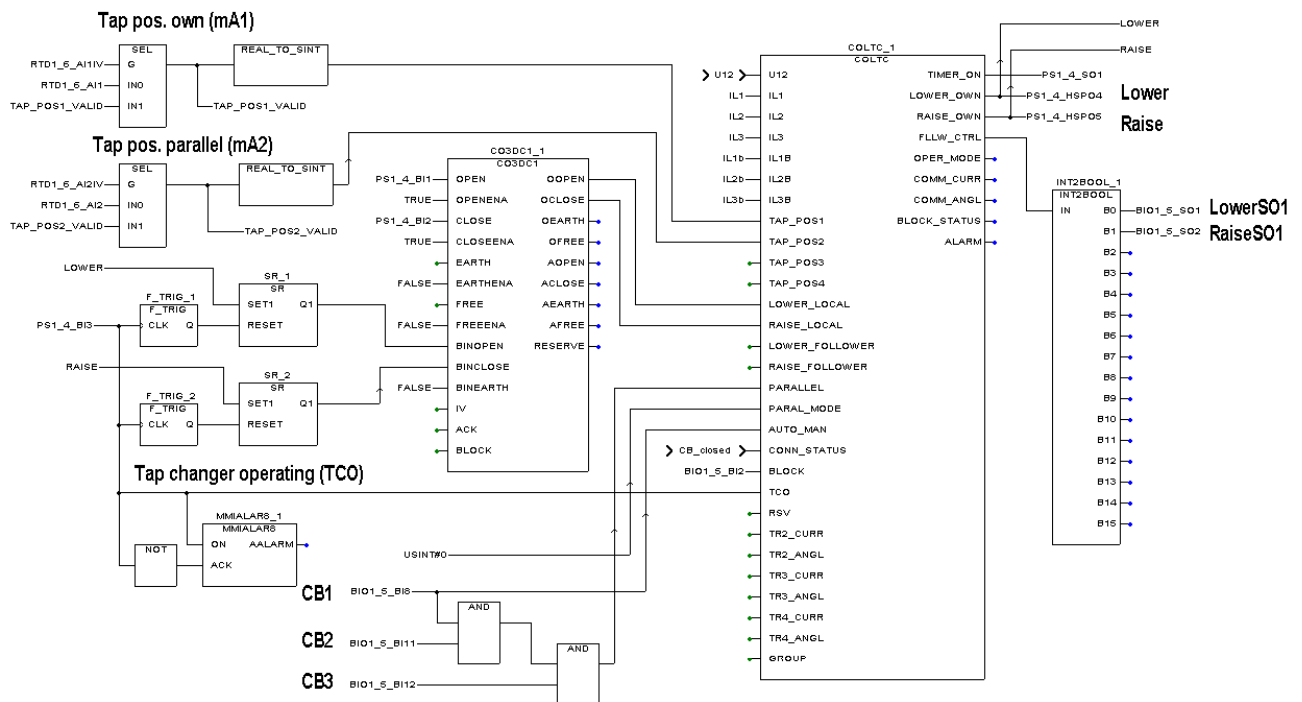


Figure 11. Regulator 1 configuration in the automatic Master/Follower example.

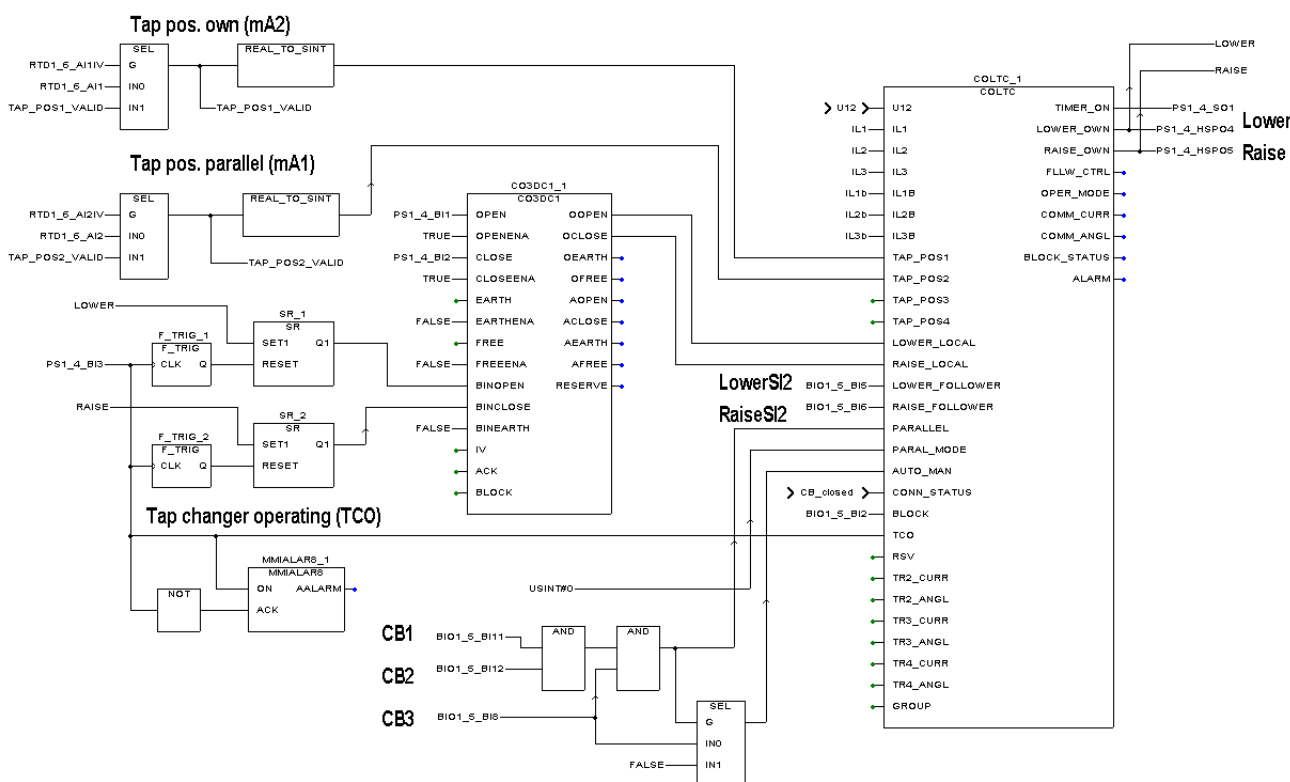


Figure 12. Regulator 2 configuration in the automatic Master/Follower example.

For the examples above the operation modes of the regulators can be described with the following table.

Table 4. The automatic selection of operation modes for regulators in the Master/Follower operation mode.

CB1	CB2	CB3	Regulator 1	Regulator 2
Open	Open	Open	Manual	Manual
Open	Open	Closed	Manual	Automatic single
Open	Closed	Open	Manual	Manual
Open	Closed	Closed	Manual	Automatic single
Closed	Open	Open	Automatic single	Manual
Closed	Open	Closed	Automatic single	Automatic single
Closed	Closed	Open	Automatic single	Manual
Closed	Closed	Closed	Automatic master	Automatic follower

If it is not possible to use LON horizontal communication between the relays and the position information (mA/resistance signal) cannot be wired from the parallel transformers, the Master/Follower principle can anyhow be used to regulate two or an unlimited number of transformers in parallel. Since the

master cannot detect the tap positions of parallel transformers, it just activates the lower and raise outputs for all followers at the moment it controls its own tap changer. This is called blind control. In this case, a number of parallel transformers are regulated as one unit. In order for the master to know that the tap positions of the followers are unknown, the tap position inputs 2...4 (TAP\_POS2..TAP\_POS4) must be left open.

Furthermore, when a disconnected transformer is taken into use, and the tap position is unknown, the operator should manually control the follower to the same position as the master.

### 3.5.2.2

#### Out-of-step function

Out-of-step function means that master is able to detect the position values of the followers and control them to the same position as master is. In this case, the master assumes that the followers also have either “Max.volt.tap.” > “Min.volt.tap.” or “Min.volt.tap.” > “Max.volt.tap.”, because this defines what is the given command pulse for a follower. If, for some reason, the master has “Max.volt.tap.” > “Min.volt.tap.” and the follower has “Min.volt.tap.” > “Max.volt.tap.” or vice versa, then the corresponding unpacked LOWER\_FOLLOWER and RAISE\_FOLLOWER inputs should be connected crosswise!

It is important to note that the Master/Follower operation mode is the only parallel mode, which has an out-of-step functionality. In the MCC and NRP operation modes the circulating current is minimized, which most probably means different tap positions in the parallel transformers. Moreover, these modes allow different ratings and step voltages for the parallel transformers. Therefore, it is reasonable to apply the out-of-step function to the Master/Follower operation mode only.

The out-of-step function is triggered when the master detects a difference of at least one step between the tap changer positions in the follower and in the master. The master then sends special raise or lower commands to the diverged follower. If two consecutive commands fail to change the position of the follower to the right direction, the master will send an event, 144E19 “Paralleling failure/Activated”, and stop these special recovery efforts. However, every time the master controls its own tap changer later, it will always send a controlling pulse to the diverged follower, as well. Furthermore, if the master notices a correct position change after a sent pulse, it will restart the attempts to drive the follower to the same position, and the event 144E18 “Paralleling failure/Reset” is sent. Note, that if there still are diverged followers, the reset event is not generated. This event is generated only when no diverged followers exists. Monitoring, and hence creation of a paralleling failure event is not possible in blind control.

The followers that have parallel failure can be read from output data “Failed followers”, which is a three-bit field. For example, if the most significant bit is active and the others inactive (“100”), it indicates that follower 4 is in parallel failure state.

## 3.5.3

**Minimizing Circulating Current (MCC) mode**

The MCC principle is the optimal solution for controlling parallel transformers of different ratings or step voltages in substations with varying reactive loads. Since this control scheme allows the exchange of data between regulators, the circulating current can be calculated more exactly than with other schemes. However, a maximum of four regulators can be connected in parallel. To start the parallel operation, the operation mode parameter has to be set to “MCC” for all the regulators of the connection. Furthermore, the signal CONN\_STATUS must indicate that the transformers are connected to the network (see section Network connection status input). Note, that a unit that is minimizing circulating current must have the operation mode set to “MCC”. However, units that have the operation mode set to “Manual” do not perform any circulating current minimization operations themselves.

Figure 13 shows a graphical presentation of the circulating current between two parallel transformers.

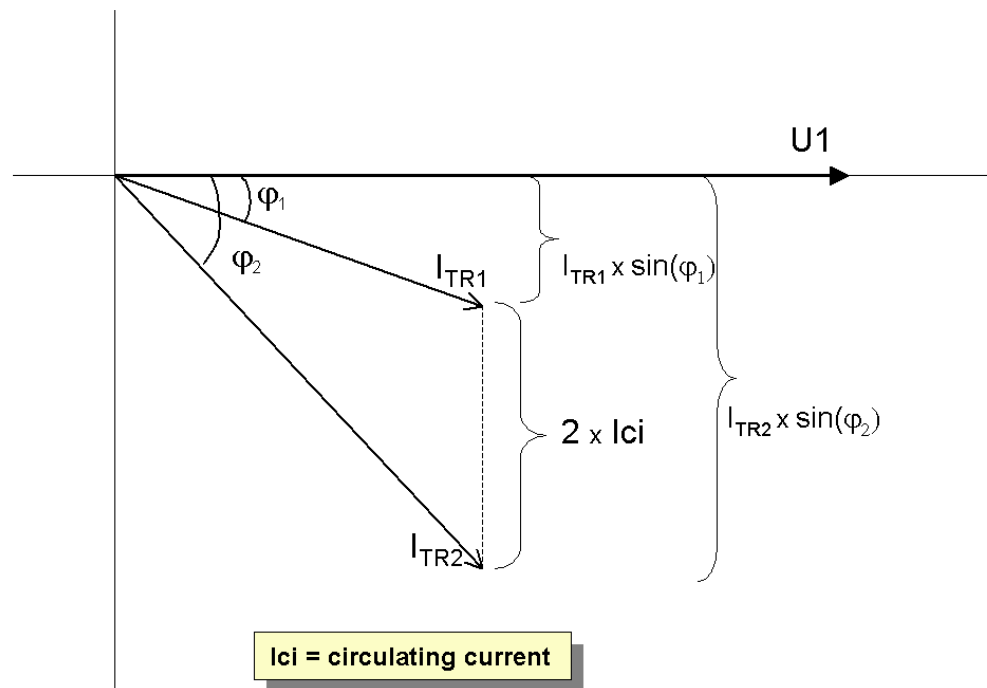


Figure 13. The circulating current between two parallel transformers.

In this case the circulating current can be calculated by the following formula.

$$I_{ci} = (\sin \varphi_1 \times I_{TR1} - \sin \varphi_2 \times I_{TR2}) / 2 \quad \text{Eq. 6}$$

in which  $I_{TR1}$  and  $I_{TR2}$  are the magnitudes and  $\varphi_1$  and  $\varphi_2$  the phase angles between the calculated voltage  $U1$  and the lowest connected secondary current (see Figure 13 and section The analog signals of the regulator). The circulating current can be read from the output data “Circ. current”.

Using the circulating current, a compensation term  $U_{ci}$  can be calculated in a following way:

$$U_{ci} = \frac{-I_{ci}}{I_n} \times \frac{Stability}{100} \times U_n \quad \text{Eq. 7}$$

in which  $I_{ci}$  is the circulating current,  $I_n$  is the nominal current of the transformer, *Stability* is the stability setting, the recommended value, which depends on the loop impedance, and  $U_n$  is the nominal voltage of the transformer.

$U_{ci}$ , which can be positive or negative, is taken into account by adding it to the reference voltage  $U_s$  (see Eq. 3).

As can be seen in Figure 13 and Eq. 6, the phasor information from the other relays is needed. Therefore, LON horizontal communication is needed between relays when the MCC principle is used. Figure 14 shows the principle how the connection is done between two regulators.

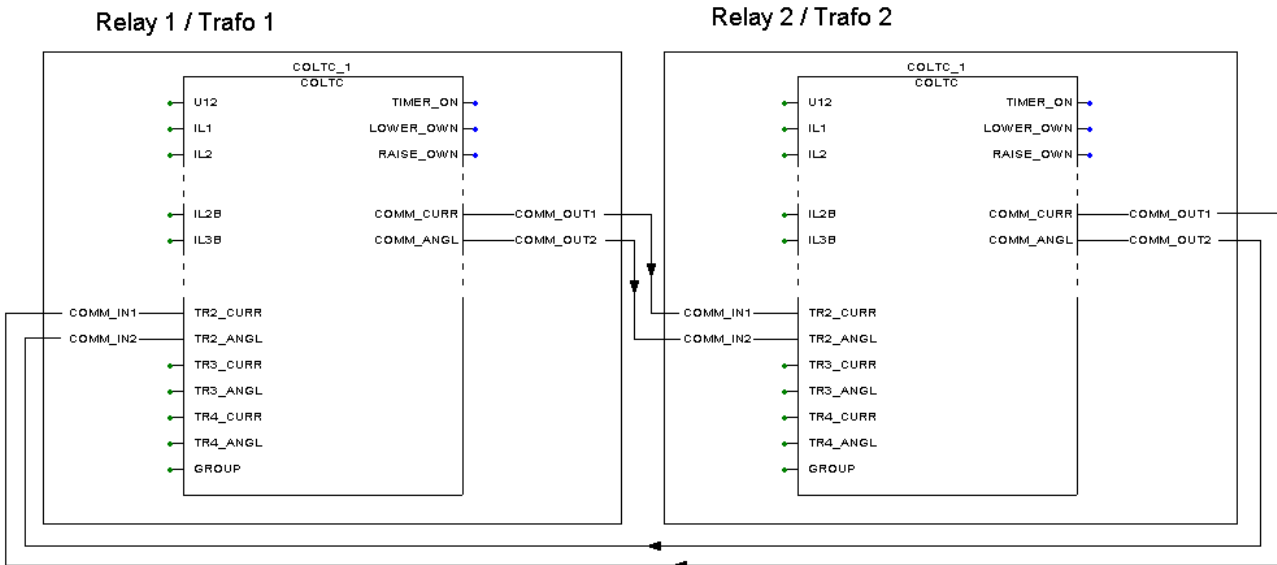


Figure 14. Two parallel transformers and horizontal connection via LON to transfer current and phase angle information when MCC principle is used.

### 3.5.3.1

#### Parallel unit detection

The network connection status information is essential for the MCC operation mode. The status needs to be connected to the input *CONN\_STATUS* in order to ensure proper operation of the MCC calculation in case that the transformer is disconnected, and COLTC is left in MCC mode. In this way the disconnected transformer is excluded from the circulating current calculations.

It is possible to check which transformers are involved in circulating current minimization by reading the output data “Parall. units MCC”, which is a three-bit field. For example, the value “011” indicates that transformers 2 and 3 are involved in calculation and transformer 4 is not. This bit is set to FALSE (=“0”) e.g. if a communication failure for the transformer occurs (see section Communication).

### 3.5.3.2

#### Communication

The phasor information from the other parallel relays is needed for the circular current calculation. Therefore, LON horizontal communication is needed between relays when the MCC principle is used.

The transferred current contains a primary value of the measured current presented with the lowest 15 bits. This enables the effective operating range 0...32767 A. The most significant bit (16th, msb) is reserved for simple communication supervision. The angle communication input also contains additional information required by the controlling algorithm. The angle information has been converted to a degree value between 0 and 359. The phase angle information structure is presented in Figure 15. The received current magnitude and phase angle information can be read from the input data “Trafo x current” and “Trafo x angle” for the magnitude and the phase angle, respectively. The x is here the connected parallel transformer number, a value between 2 and 4. The magnitude is given as a primary value and the angle is between –180...+180 degrees.

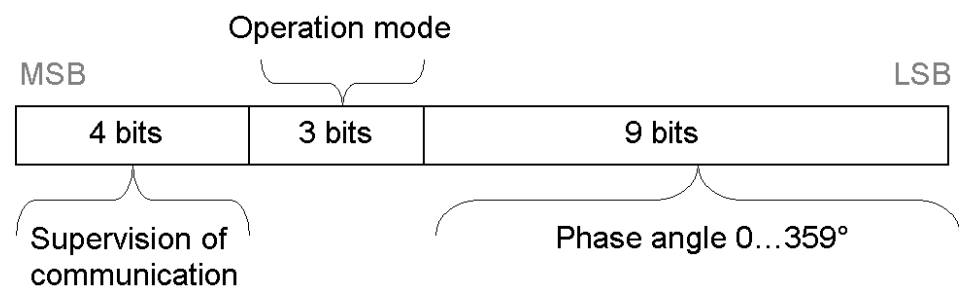


Figure 15. The communicated phase angle information structure

The sent phase angle always represents the angle between the voltage phasor, U1 (which is not directly connected, but one of the main voltages U12, U23 or U31) and IL1b. If the IL1b (or U12) measurement is not available, COLTC will calculate it virtually using the phasor from IL2b or IL3b (U23 or U31) as a reference, assuming a symmetrical 3-phase network. Packed information regarding the current phasor can be read from the output data “Output COMM\_CURR” and “Output COMM\_ANGL”. In order to understand the information in these packed values they must be decoded. The communication can be seen to be active when these output values change their value every 500 milliseconds.



The first activation of the communication error (value differs from “000000000000”) results in event 144E23, “Communication error/Activated” sending. The communication error is reset (i.e., the corresponding event 144E22 “Communication error/Reset” is sent), when no communication failures longer exists. In this case, also the output data “Communic. error” has the value “000000000000”. These events are not, however, involved in the default event mask. The event has a integer type data field, where the corresponding word- bit field has been converted to integer.

If one of the TRx\_CURR/TRx\_ANGL pairs is left unconnected, no communication error for this transformer is generated. The output data “Communic. Error” bits for this transformer remains FALSE.

*Table 5. Communication error numbering*

Bit 0	Packet number failure for transformer 2, phase
Bit 1	Packet number failure for transformer 3, phase
Bit 2	Packet number failure for transformer 4, phase
Bit 3	Communication timeout for transformer 2, phase
Bit 4	Communication timeout for transformer 3, phase
Bit 5	Communication timeout for transformer 4, phase
Bit 6	Operation mode failure for transformer 2, phase
Bit 7	Operation mode failure for transformer 3, phase
Bit 8	Operation mode failure for transformer 4, phase
Bit 9	Communication timeout for transformer 2, magnitude
Bit 10	Communication timeout for transformer 3, magnitude
Bit 11	Communication timeout for transformer 4, magnitude

### 3.5.4

#### Negative Reactance Principle (NRP)

This parallel control scheme is suitable for power transformers with different ratings and step voltages. Since no communication between the regulators is needed, this principle can be applied even when the parallel transformers are located at different substations. To start parallel operation, the operation mode has to be set “NRP” (=Negative Reactance Principle) for all the regulators of the connection. The operation mode can be changed via function block inputs or by setting either locally or remotely.

When applying this principle each regulator has a phase angle setting  $\varphi_{Load}$  (setting parameter “Load phase angle”) towards which it tries to regulate the current. The setting value is chosen according to the expected power factor of the load (positive setting value equals inductive load). When the actual phase angle of the load current is the same as the setting and the transformers and their tap changer positions are identical, the currents of the two or more transformers are in the same phase as the total load current. If on the other hand the tap changer positions are different, a circulating current flows and the currents of the different transformers either lag or lead the load current. Figure

16 below shows that the circulating current is the reactive component, which separates the measured current vector from the expected angle value.

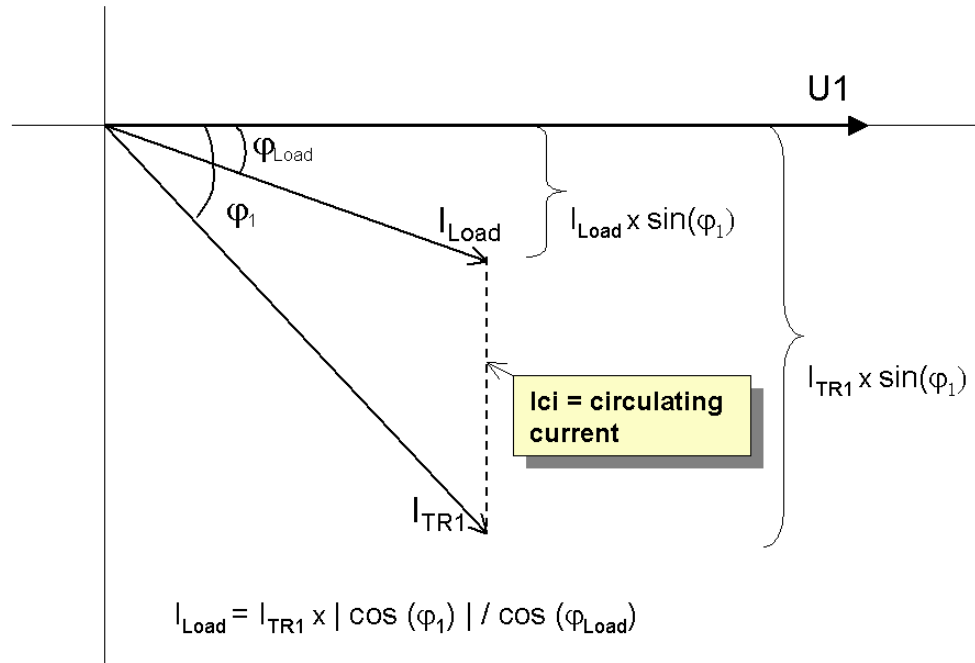


Figure 16. The expected phase angle of the load supplied by the transformers operating in parallel is entered as a setting value ( $\varphi_{Load}$ ).

The regulators calculate the circulating current by the following formula (see Figure 16):

$$I_{ci} = (\sin \varphi_1 - \tan \varphi_{Load} \times |\cos \varphi_1|) \times I_{TR1} \quad \text{Eq. 8}$$

in which  $I_{TR1}$  is the current measured by the regulator and  $\varphi_1$  is phase angle between calculated voltage  $U_1$  and lowest connected secondary current.  $\varphi_{Load}$  is the set phase angle of the load current.

In the negative reactance method the circulating current is minimized by changing the control voltage according to the measured circulating current. The regulator calculates the circulating current compensation term  $U_{ci}$  (Eq. 3) in a same manner as in the MCC –principle:

$$U_{ci} = \frac{-I_{ci}}{I_n} \times \frac{Stability}{100} \times U_n \quad \text{Eq. 9}$$

If the parallel operating transformers have different rated currents, the regulator stability setting value should be proportional to the rated currents, i.e. the higher the rated current the higher the stability setting value.

By comparing the reactive components of the currents measured by the different regulators it is possible to find out, if the circulating current has been minimized. The circulating current has been minimized, when the reactive components are practically equal to each other.

It should be noted that the negative reactance method will give satisfactory results only if the phase angle of the load current is known relatively accurately. If the actual phase angle deviates from the phase angle setting, this will result in a regulating error. However, for the cases where there is an occasional stepwise change in the phase angle of the load, the regulating error can be suppressed with the IEC61131-3 logic. This kind of stepwise change can occur for example when a capacitor bank is switched on to compensate a reactive power flow. The next figure illustrates an example on how the logic can be built.

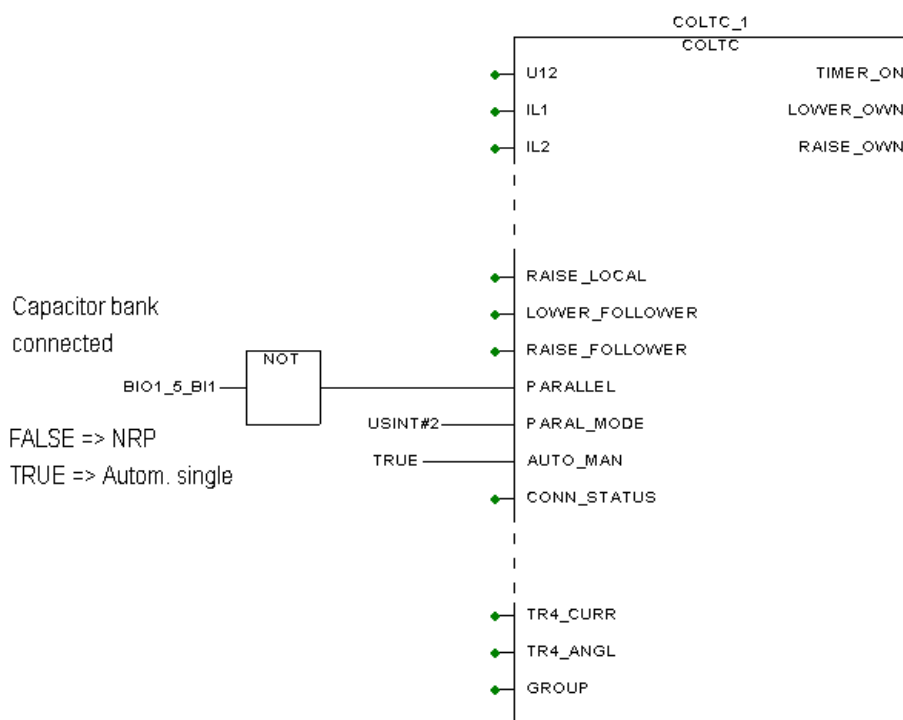


Figure 17. Changing the operation mode of COLTC automatically, when the capacitor bank is connected.

Another possibility would be to use GROUP-input for automatic changing between setting group 1 and 2 in different loading situations. Setting groups would then have different set value for the load angle.

### 3.5.5

### Comparison Summary

The parallel operation modes are needed because if the parallel regulators operated independently, sooner or later the transformers would be out of step with each other.

The circulating current would increase and the line drop compensation would thus increase for the transformer giving highest voltage. Correspondingly, the increasing circulating current would cause the transformer giving lowest voltage to decrease voltage due to decreased line drop compensation effect. In other words, the two transformers would run apart.

However, it is case-specific which one of the parallel operation modes is the most suitable. The chapters below summarize disadvantages and advantages for different parallel operation modes presented in previous chapters.

The following is a list of disadvantages (-) and advantages (+) of the different operating modes.

#### **Master/Follower (follower positions not known by master)**

- Requires power transformers with identical ratings and step voltages
- Extra wiring work: Raise/Lower commands (extracted from output FLLW\_CTRL) from the master to the follower
- Manual control needed when follower positions become differentiated from the master and in the beginning of operation
- + Parallel transformers are regulated as one unit
- + Supports unlimited number of transformers in parallel

#### **Master/Follower (follower positions known)**

- Requires power transformers with identical ratings and step voltages
- Extra wiring work: Raise/Lower commands (extracted from output FLLW\_CTRL) from the master to the follower, position information from followers to the master
- + Out-of-step function, i.e. automatic detection and correction when the follower position deviates from the master
- + Parallel transformers are regulated as one unit

#### **Negative Reactance Principle**

- If the measured phase angle of the load current deviates from the set phase angle, this will result in a regulating error
- When line drop compensation is used, the setting should be changed when number of transformers in parallel operation is changed
- + The step voltages and short circuit impedances of the transformers do not need to be identical
- + No communication nor wiring between regulators is needed, meaning that the principle can be applied even when the parallel transformers are located at different substations

- + Supports unlimited number of transformers in parallel

### Minimizing Circulating Current

- Requires extra configuration efforts, since this principle utilizes LON horizontal communication between regulators
- + The step voltages and short circuit impedances of the transformers do not need to be identical
- + The phase angle of the load current may vary without any impact on the accuracy of regulation
- + Automatic adjustment for number of transformers (needed for accurate calculation of line drop compensation term)

## 3.6

### Blockings

The operation of the voltage regulator may be blocked for several reasons. The purpose of blocking is to prevent the tap changer from operating under conditions that can damage the tap changer, or exceed other power system related limits. There is the BLOCK\_STATUS output, (see section BLOCK\_STATUS Output) that does not imply actual blocking but reveals if the coming command pulse will be issued or not. Blocking itself happens when the corresponding bit in signal BLOCK\_STATUS is active and command pulse is to be started due timer elapse or local command. Reason for this approach is that we will avoid unnecessary event sending. Table 6 later shows an overview how blockings are operated.

In Table 6, a cross (X) defines when operation is blocked (if the corresponding bit is active in BLOCK\_STATUS). For example, over voltage results to blocking only when operation mode is "Manual" and manual raise command is to be given.

Table 6. Blocking schema in COLTC.

Operation mode	Command	Over-current	Under-voltage	Over-voltage	High circulating current	External Block	Extreme positions
Manual	RAISE_LOCAL	X		X			X
	LOWER_LOCAL	X					X
Autom.follower	RAISE_FOLLOWER	X	X			X	X
	LOWER_FOLLOWER	X	X			X	X
Autom. single,, Autom. master,, NRP, MCC	Automatic raise	X	X		X **)	X	X *)
	Automatic lower	X	X		X **)	X	X *)

\*) However, event is not sent in these cases because pure automatic operation notices that extreme position has already been reached. Automatic follower case can here more or less be compared to manual case and events are sent.

\*\*) Because circulating current is only calculated in modes NRP and MCC, it can have blocking effect only in these modes.

### 3.6.1

#### Overcurrent

Overcurrent blocking is mainly used for preventing the tap changer from operating in an overcurrent situation. For example, if the current is not high enough to activate the protective relay of the substation but still fatal for the diverter switch of the tap changer. This operation can be adjusted with the control setting parameter "Overcurr. limit". It is recommended to base the overcurrent blocking on the current(s) measured on the primary side of the transformer, where maximum of peak value measurements of all connected phases has been selected. This maximum value can be read from input data "Primary current". In this way the blocking will work even at the internal faults of the transformer. Only if none of primary side currents is connected, then maximum of rms-value measurements of all connected phases from secondary side has been selected. This maximum value can be read from input data "Second. current". Both the automatic operation and the manual operation are blocked (see Table 6) when the set limit is exceeded.

Blocking activation generates event 144E9 "Over current blocking/Activated" and MMI indication text "COLTC: BLOCK Internal". Blocking reset generates event 144E8 "Over current blocking/Reset". Blocking status can be read from output data "Block OverCurr".

### 3.6.2

#### Undervoltage

The undervoltage blocking feature blocks both raise and lower voltage commands if, for some reason, the measured voltage, is too low to be corrected by operating the tap changer. Such a situation may be due to a faulty measuring circuit, an earth-fault or and overcurrent situation. Only the automatic (also automatic follower) operation is blocked when the undervoltage condition is met (see Table 6). This operation can be adjusted with the setting parameter "Undervolt. limit".

Blocking activation generates event 144E11 "Under voltage blocking/Activated" and MMI indication text "COLTC: BLOCK Internal". Blocking reset generates event 144E10 "Under voltage blocking/Reset". Blocking status can be read from output data "Block UnderVolt".

However, there is no minimum limit for undervoltage blocking. We allow blocking although measured voltage is not connected or it has temporarily very low value. Note, however, that there is minimum limit for phase angle calculation based on voltage phasor (see section The analog signals of the regulator).

### 3.6.3

#### Overvoltage

The manual raise command is blocked if the overvoltage limit is exceeded (see Table 6). However, in the automatic operation mode the overvoltage situation triggers the "fast lower" feature. See chapter Fast Lower Control for

further details. This operation can be adjusted with the setting parameter "Overvolt. limit".

Blocking activation generates event 144E13 "Over voltage blocking/Activated" and MMI indication text "COLTC: BLOCK Internal". Blocking reset generates event 144E12 "Over voltage blocking/Reset". Blocking status can be read from output data "Block OverVolt".

### 3.6.4 High Circulating Current

The circulating current value is calculated in the operation modes: Negative Reactance Principle (NRP) and Minimizing Circulating Current (MCC). Only the automatic operation in these modes is blocked when the high circulating current is measured (see Table 6). This operation can be adjusted with the setting parameter "Circ.curr. limit".

Blocking activation generates event 144E15 " High circ. current blocking/Activated" and MMI indication text "COLTC: BLOCK Internal". Blocking reset generates event 144E14 "High circ. current blocking /Reset". Blocking status can be read from output data "Block Circ.curr.".

### 3.6.5 BLOCK – Function Block Input

Using IEC61131-3 configuration possibilities one can build a desired blocking condition and connect an outcome to this input. When activated this input blocks only the automatic operation of the regulator (see Table 6). However, it is also possible to build an extra logic for blocking manual commands during certain situation by using OPENENA and CLOSEENA inputs of the CO3DC1 function block. See the inputs for example in Figure 3 and refer the manual of CO3DC1 for detailed information of the usage of the inputs.

Blocking activation generates event 144E17 "External input blocking/Activated" and MMI indication text "COLTC: BLOCK External". Blocking reset generates event 144E16 "External input blocking /Reset". Blocking status can be read from output data "Block ExtBlock".

### 3.6.6 Extreme Positions

This blocking function supervises the extreme positions of the tap changer. These extreme positions can be adjusted with the setting parameters "Max.volt.tap" and "Min.volt.tap". When the tap changer reaches one of these two positions, further commands in the corresponding direction is blocked (see Table 6) and an event is sent indicating unsuccessful command. Note that here it depends on the comparison between settings "Max.volt.tap" and "Min.volt.tap.", which direction is blocked (see section Voltage control vs. tap changer moving direction). This blocking affects both the automatic and manual operation modes. However, like told in Table 6, no events are to be

generated in pure automatic modes. Here "Autom. follower" is not a pure automatic mode. Extreme position blocking activation generates event 144E25 "TC already in extreme position" and MMI indication text "COLTC: BLOCK Extreme pos.". Unconnected position information does not cause "total block of COLTC", only extreme position blocking is not working.

### 3.7

#### Fast Lower Control

COLTC provides the "fast lower control" in the automatic operation modes. When the set overvoltage limit "Overvolt. limit" is exceeded the regulator gives fast lower control pulses until the voltage falls below the specified limit.

Blocking activation generates event 144E13 "Over voltage blocking/Activated" and MMI indication text "COLTC: BLOCK Internal". Blocking reset generates event 144E12 "Over voltage blocking/Reset". Blocking status can be read from output data "Block OverVolt".

A remarkable difference in this operation is that although blocking is reset after undershooting the above named limit, the "fast lower control" operation continues until the measured voltage signal undershoots "Bandwidth"-hysteresis limit (see Figure 7). As a result, normal automatic mode operation is not possible before this happens.

Fast lower control causes successive LOWER\_OWN pulses to be activated. Time between consecutive pulse starts is 1.5 seconds. This means, that 1) there is no tap changer operating delay (otherwise 6 seconds) taken into account in this cycle (meaning that some command pulses are ineffective due to tap changer operation, see section Tap changer operating (TCO) input), 2) timer mode set by "Delay mode" has no effect here (always DT timer type operation) and 3) because the default pulse length (setting "Output pulse") is also 1.5 seconds, some of the consecutive pulses do not start at all, because it is not allowed to start new command pulse if old one is still active.

Note that in the automatic follower -mode the Fast Lower is not triggered. In this way the awkward dispersion of position values in different units can be avoided. The master makes always fast lower decision on behalf of follower units. Moreover, master and follower should anyhow measure equal voltage level and have similar setting values for overvoltage blocking limit.

### 3.8

#### Tap Changer Monitoring

COLTC supervises the operation of the tap changer and alarms if the alarm condition is detected. Alarm activation means that output ALARM is activated and event 144E21 "Tap changer alarm/Activated" is generated. This event has integer type data field indicating alarm reason. Alarm reset generates event 144E20 "Tap changer alarm/Reset". Alarm reason can be read from three-bit



long bit field in output data "Alarm reason". Three different alarm conditions can be detected by COLTC:

### 3.8.1 Command error

COLTC supervises the own transformer's tap changer (connected to TAP\_POS1) position information when a control pulse is given. If the correct position change, (direction depends on the settings "Max.volt.tap. and "Min.volt.tap." comparison, see section Voltage control vs. tap changer moving direction), is not seen by COLTC in 20 seconds after pulse start, the alarm is issued.

In case the position information is not connected, no alarm is generated. The alarm is reset when the correct change in position value is detected after given pulse or if new command pulse is given.

Output data "Alarm reason" bit B0 is set during alarm. This means that if this is only active alarm reason, "Alarm reason" has value "001". However, event data field has in this case value "1".

### 3.8.2 TCO signal does not fall

If tap changer operating –signal (TCO) stays active more than 15s after output pulse deactivation, COLTC concludes this as an abnormal condition assuming tap changer stuck. Alarm is reset when TCO signal inactivates. Output data "Alarm reason" bit B1 is set during alarm. This means that if this is only active alarm reason, "Alarm reason" has value "010". However, event data field has in this case value "2".

If the TCO-signal is not connected, this type of alarm is not possible.

### 3.8.3 Regulator pumping

It is possible that faulty settings will cause the regulator to give control pulses too frequently. For example, too low setting for the bandwidth ( $\Delta U_s$ , see Figure 7) may result in a pumping condition, where the regulator has problems to bring the regulated voltage to desired level. In order to detect this COLTC has a setting parameter: "Controls per 1h", which defines the allowed number of lower and raise commands during 1 hour sliding time window. The detection is active both in manual and in automatic operation modes. The alarm is reset when the counted number of the operations during 1 hour time window is less than the set value. Number of executed operations per last one hour can be read from output data "CtrlsPerLast1h". However, note that this parameter is updated only in 3 minutes interval. Output data "Alarm reason" bit B2 is set during alarm. This means that if this is only active alarm reason, "Alarm reason" has value "100". However, event data field has in this case value "4".

The operation of COLTC is not blocked during the alarm situation, but all the alarms mentioned above will cause the automatic operation to be delayed. In practice, this means that the set delay times T1 and T2 are doubled.

In addition to alarm detections, COLTC provides an operation counter parameter (control setting "Oper. counter") for determining the service intervals of the tap changer. The counter gives the total number of raise and lower commands given in the manual and automatic modes. All commands, even those that are omitted by tap changer due to its operation sequence, are calculated in cumulative counter.

## 4. Parameters and events

### 4.1 General

- Each function block has a specific channel number for serial communication parameters and events. The channel for COLTC is 144.
- The data direction of the parameters defines the use of each parameter as follows:

Data direction	Description
R, R/M	Read only
W	Write only
R/W	Read and write

- The different event mask parameters (see section “Control Settings”) affect the visibility of events on the HMI or on the serial communication (LON or SPA) as follows:

Event mask 1 (F144V101/102)	SPA / MMI (LON)
Event mask 2 (F144V103/104)	LON
Event mask 3 (F144V105/106)	LON
Event mask 4 (F144V107/108)	LON

For example, if only the events E3, E4 and E5 are to be seen on the HMI of the relay terminal, the event mask value 56 ( $8 + 16 + 32$ ) is written to the “Event mask 1” parameter (F144V101).

## 4.2 Setting values

### 4.2.1 Actual Settings

Parameter	Code	Values	Unit	Default	Data direction	Explanation
Reference volt.	S1	0.000...2.000	x Un	1.000	R/M	The reference voltage, $U_s$
Delay time 1	S2	1.0...300.0	s	60.0	R/M	Delay time for the first control pulse
Delay time 2	S3	1.0...300.0	s	30.0	R/M	Delay time for the following control pulse
Ur [%]	S4	0.0...25.0	% Un	0.0	R/M	Resistive line-drop compensating factor
Ux [%]	S5	0.0...25.0	% Un	0.0	R/M	Reactive line-drop compensating factor
Load phase angle	S6	-89...89	°	0	R/M	Load phase-shift, used only with the Negative Reactance Principle
Stability	S7	0.0...70.0	% Un	0.0	R/M	Stability factor in parallel operation

### 4.2.2 Setting Group 1

Parameter	Code	Values	Unit	Default	Data direction	Explanation
Reference volt.	S41	0.000...2.000	x Un	1.000	R/M	The reference voltage, $U_s$
Delay time 1	S42	1.0...300.0	s	60.0	R/M	Delay time for the first control pulse
Delay time 2	S43	1.0...300.0	s	30.0	R/M	Delay time for the following control pulse
Ur [%]	S44	0.0...25.0	% Un	0.0	R/M	Resistive line-drop compensating factor
Ux [%]	S45	0.0...25.0	% Un	0.0	R/M	Reactive line-drop compensating factor
Load phase angle	S46	-89...89	°	0	R/M	Load phase-shift, used only with the Negative Reactance Principle
Stability	S47	0.0...70.0	% Un	0.0	R/M	Stability factor in parallel operation

## 4.2.3

## Setting Group 2

Parameter	Code	Values	Unit	Default	Data direction	Explanation
Reference volt.	S71	0.000...2.000	x Un	1.000	R/M	The reference voltage, $U_s$
Delay time 1	S72	1.0...300.0	s	60.0	R/M	Delay time for the first control pulse
Delay time 2	S73	1.0...300.0	s	30.0	R/M	Delay time for the following control pulse
$U_r$ [%]	S74	0.0...25.0	% Un	0.0	R/M	Resistive line-drop compensating factor
$U_x$ [%]	S75	0.0...25.0	% Un	0.0	R/M	Reactive line-drop compensating factor
Load phase angle	S76	-89...89	°	0	R/M	Load phase-shift, used only with the Negative Reactance Principle
Stability	S77	0.0...70.0	% Un	0.0	R/M	Stability factor in parallel operation

## 4.2.4 Control Settings

Parameter	Code	Values	Unit	Default	Data direction	Explanation
Operation mode	V1	0...7 <sup>1)</sup>	-	1	R/W	The operation mode of COLTC
Delay mode	V2	0...1 <sup>2)</sup>	-	0	R/W	Selection for time delays 1 and 2 - Definite or Inverse
Group selection	V3	0...2 <sup>3)</sup>	-	0	R/W	Selection of the active setting group
Active group	V4	0...1 <sup>4)</sup>	-	0	R/M	Active setting group
Output pulse	V5	0.5...10.0	s	1.5	R/W	Output pulse duration, common for raise and lower pulses
Bandwidth	V6	0.60...9.00	% Un	1.5	R/W	Allowed deviation of the control voltage
Overcurr. limit	V8	0.10...5.00	x In	2.00	R/W	Overcurrent blocking limit
Undervolt. limit	V9	0.10...1.20	x Un	0.70	R/W	Undervoltage blocking limit
Overvolt. limit	V10	0.80...1.60	x Un	1.25	R/W	Overvoltage blocking limit
Min.volt.tap.	V11	-36...36	-	0	R/W	Tap changer limit position which gives lowest voltage on the regulated side
Max.volt.tap.	V12	-36...36	-	17	R/W	Tap changer limit position which gives highest voltage on the regulated side
Circ.curr. limit	V13	0.10...5.00	x In	0.15	R/W	Blocking limit for high circulating current
LDC limit	V14	0.00...2.00	x Un	0.10	R/W	Maximum limit for line drop compensation term
LDC selection	V15	0...1 <sup>5)</sup>	-	0	R/W	Selection for line drop compensation
RSV step	V16	0.00...9.00	% Un	0.00	R/W	Step size for Reduce Set Voltage (RSV)
Parallel trafos	V17	0...10	-	0	R/W	Number of parallel transformers in addition to own transformer
Controls per 1h	V18	0...10000	-	100	R/W	Allowed number of controls per one hour, sliding window
Oper. counter	V19	0...65535	-	0	R/W	Total number of raise and lower commands given in the manual and automatic modes
Event mask 1	V101	0...721420223	-	708837120	R/W	Event mask 1 for event transmission (E0 ... E25)
Event mask 2	V103	0...721420223	-	708837120	R/W	Event mask 2 for event transmission (E0 ... E25)
Event mask 3	V105	0...721420223	-	708837120	R/W	Event mask 3 for event transmission (E0 ... E25)
Event mask 4	V107	0...721420223	-	708837120	R/W	Event mask 4 for event transmission (E0 ... E25)

- 1) Operation mode      0 = Not in use; 1 = Manual; 2 = Autom. single; 3 = Autom. master; 4 = Autom. follower; 5 = NRP; 6 = MCC; 7 = Op.mode inputs
- 2) Delay mode          0 = Definite time; 1 = Inverse time
- 3) Group selection      0 = Group 1; 1 = Group 2; 2 = GROUP input
- 4) Active group        0 = Group 1; 1 = Group 2
- 5) LDC active           0 = OFF; 1 = ON

## 4.3 Measurement values

### 4.3.1 Input Data

Parameter	Code	Values	Unit	Default	Data direction	Explanation
Voltage U12	I1	0.000...2.000	x Un	0.000	R/M	Phase-to-phase voltage U12 (LV side), average filtered
Primary current	I2	0.00...60.00	x In	0.00	R/M	Primary current (HV side) maximum of three phases, peak measurement
Second. current	I3	0.00...60.00	x In	0.00	R/M	Secondary current (LV side) maximum of three phases, rms measurement
Angle U1-IL1	I4	-180...180	°	0	R/M	Measured angle value between U1 and IL1 (LV side)
Input TAP_POS1	I5	-36...99	-	99	R/M	Integer value representing tap changer position for transformer 1 (own transformer)
Input TAP_POS2	I6	-36...99	-	99	R/M	Integer value representing tap changer position for transformer 2
Input TAP_POS3	I7	-36...99	-	99	R/M	Integer value representing tap changer position for transformer 3
Input TAP_POS4	I8	-36...99	-	99	R/M	Integer value representing tap changer position for transformer 4
Input BLOCK	I9	0 or 1 <sup>1)</sup>	-	0	R/M	External blocking signal
Input TCO	I10	0 or 1 <sup>1)</sup>	-	0	R/M	Tap changer operating input
Input RSV	I11	0...65535	-	0	R/M	Reduce set voltage input
Trafo 2 current	I12	0...20000	A	0	R/M	Current from transformer 2
Trafo 2 angle	I13	-180...180	°	0	R/M	Angle between U1 and IL1 from transformer 2
Trafo 3 current	I14	0...20000	A	0	R/M	Current from transformer 3
Trafo 3 angle	I15	-180...180	°	0	R/M	Angle between U1 and IL1 from transformer 3
Trafo 4 current	I16	0...20000	A	0	R/M	Current from transformer 4
Trafo 4 angle	I17	-180...180	°	0	R/M	Angle between U1 and IL1 from transformer 4
Input GROUP	I18	0 or 1 <sup>1)</sup>	-	0	R/M	Control input for switching between setting group 1 and setting group 2

<sup>1)</sup> Active

0 = Not active; 1 = Active

### 4.3.2 Output Data

Parameter	Code	Values	Unit	Default	Data direction	Explanation
Control voltage	O1	0.000...2.000	x Un	0.000	R/M	Control voltage, Up, target voltage level of COLTC
dU	O2	-2.000...2.000	x Un	0.000	R/M	Voltage difference between Measured voltage - Control Voltage: $U_m - U_p$
Circ. current	O3	-60.00...60.00	x In	0.00	R/M	Calculated circulating current - calculated in operation modes NRP and MCC
LDC	O4	0.000...2.000	x Un	0.000	R/M	Calculated Line Drop Compensation
Output TIMER_ON	O5	0...1 <sup>1)</sup>	-	0	R/M	Timer T1, T2 or Fast Lower Control active
Output LOWER_OWN	O6	0...1 <sup>1)</sup>	-	0	R/M	Lower command pulse for own transformer
Output RAISE_OWN	O7	0...1 <sup>1)</sup>	-	0	R/M	Raise command pulse for own transformer
Output FLLW_CTRL	O8	0...63 <sup>2)</sup>	-	0	R/M	Lower and raise command pulses for follower transformers in the Master/Follower operation mode
Output OPER_MODE	O9	0...6 <sup>3)</sup>	-	1	R/M	Active operation mode of COLTC; selected either with FB inputs or via setting
Output COMM_CURR	O10	0...65535	-	0	R/M	Measured amplitude of current + additional information to be sent via horizontal communication
Output COMM_ANGL	O11	0...65535	-	0	R/M	Measured angle + additional information to be sent via horizontal communication
Block OverCurr	O12	0...1 <sup>1)</sup>	-	0	R/M	Indication of overcurrent blocking
Block UnderVolt	O13	0...1 <sup>1)</sup>	-	0	R/M	Indication of undervoltage blocking
Block OverVolt	O14	0...1 <sup>1)</sup>	-	0	R/M	Indication of overvoltage blocking
Block ExtBlock	O15	0...1 <sup>1)</sup>	-	0	R/M	Indication of external blocking
Block Circ.curr.	O16	0...1 <sup>1)</sup>	-	0	R/M	Indication of high circulating current blocking
Alarm reason	O17	0...7 <sup>4)</sup>	-	0	R/M	Status and reason for alarm
CtrlsPerLast1h	O18	0...65535	-	0	R/M	Number of controls in own tap changer during last hour
Failed followers	O19	0...7 <sup>5)</sup>	-	0	R/M	Failed followers
Communic. error	O20	0...4095 <sup>6)</sup>	-	0	R/M	Communication error
Parall.units MCC	O21	0...7 <sup>7)</sup>	-	0	R/M	Parallel units included in MCC calculation

1) Active

0 = Not active; 1 = Active

2) Followers

B0 = Lower follower 2; B1 = Raise follower 2; B2 = Lower follower 3; B3 = Raise follower 3; B4 = Lower follower 4; B5 = Raise follower 4

3) Operation mode

0 = Not in use; 1 = Manual; 2 = Autom. single; 3 = Autom. master; 4 = Autom. follower; 5 = NRP; 6 = MCC

4) Alarm type

B0 = TC command; B1 = TCO signal; B2 = Commands per 1h

5) Failed follower(s)

B0 = Follower 2; B1 = Follower 3; B2 = Follower 4

6) Communication error

B0 = Packet nr Tr2; B1 = Packet nr Tr3; B2 = Packet nr Tr4; B3 = Delay angle Tr2; B4 = Delay angle Tr3; B5 = Delay angle Tr4; B6 = Oper.mode Tr2; B7 = Oper.mode Tr3; B8 = Oper.mode Tr4; B9 = Delay ampl. Tr2; B10 = Delay ampl. Tr3; B11 = Delay ampl. Tr4

7) Parallel units MCC

B0 = Trafo 2; B1 = Trafo 3; B2 = Trafo 4



## 4.3.3

## Event Codes

Code	Weighting coefficient	Default mask	Event reason	Event state
E0	1	0	Operation timer	Reset
E1	2	0	Operation timer	Activated
E2	4	0	Voltage raise output signal	Reset
E3	8	0	Voltage raise output signal	Activated
E4	16	0	Voltage lower output signal	Reset
E5	32	0	Voltage lower output signal	Activated
E6	0	0	-	-
E7	128	0	RSV input change	-
E8	256	1	Overcurrent blocking	Reset
E9	512	1	Overcurrent blocking	Activated
E10	1024	1	Undervoltage blocking	Reset
E11	2048	1	Undervoltage blocking	Activated
E12	4096	1	Overvoltage blocking	Reset
E13	8192	1	Overvoltage blocking	Activated
E14	16384	1	High circ. current blocking	Reset
E15	32768	1	High circ. current blocking	Activated
E16	65536	1	External input blocking	Reset
E17	131072	1	External input blocking	Activated
E18	262144	1	Paralleling failure	Reset
E19	524288	1	Paralleling failure	Activated
E20	1048576	1	Tap changer alarm	Reset
E21	2097152	1	Tap changer alarm	Activated
E22	4194304	0	Communication error	Reset
E23	8388608	0	Communication error	Activated
E24	0	0	-	-
E25	33554432	1	TC already in extreme position	-
E26	0	0	-	-
E27	134217728	1	Operation mode of COLTC	-
E28	0	0	-	-
E29	536870912	1	TC position value change	-

## 5. Technical data

<b>Operation accuracies</b>	<p>Voltage measurement:</p> <p>Depends on the frequency of the voltage measured:</p> $f/f_n = 0.95 \dots 1.05: \pm 1.0\% \text{ of set value or } \pm 0.01 \times U_n$ <p>Operation time:</p> <p>DT mode: <math>\pm 1\%</math> of the set value OR <math>\pm 250\text{ms}</math></p> <p>IDMT mode: <math>\pm 250 \text{ ms}</math> AND an inaccuracy which occurs when the voltage signal varies <math>\pm 0,5\%</math></p> <p>Also note that the minimum operate time in IDMT mode is 1,0 s.</p> <p>Lower and raise output pulse duration:</p> $\pm 100 \text{ ms}$ <p>Note that the accuracy depends on the function block execution interval (that can be selected) and the "Output pulse" setting value.</p>
<b>Reset ratio (hysteresis)</b>	$ U_{\text{start}} - U_{\text{reset}}  = 20\% \text{ of the set Bandwidth}$
<b>Configuration data</b>	<p>Task execution interval (Relay Configuration Tool): <math>\leq 100 \text{ ms}</math></p> <p>at the rated frequency <math>f_n = 50 \text{ Hz}</math></p>