The ABB Guide to

Circuit Breaker Selection for protection and switching of **400V Transformers**

Transformer 400V		
Sr	Uk	Trafo Ir
[kA]	%	[A]
1 x 63	4	91
2 x 63		91
1 x 100	4	144
2 x 100		144
1 x 125	4	180
2 x 125		180
1 x 160	4	231
2 x 160		231
1 x 200	4	289
2 x 200		289
1 x 250	4	361
2 x 250		361
1 x 315	4	455
2 x 315		455
1 x 400	4	577
2 x 400		577
1 x 500	4	722
2 x 500	4	722
1 x 630		909
2 x 630		909
3 x 630		909
1 x 800	5	1155
2 x 800		1155
3 x 800		1155
1 x 1000	5	1443
2 x 1000		1443
3 x 1000		1443
1 x 1250	5	1804
2 x 1250		1804
3 x 1250		1804
1 x 1600	6.25	2309
2 x 1600		2309
3 x 1600		2309
1 x 2000	6.25	2887
2 x 2000		2887
3 x 2000		2887
1 x 2500	6.25	3608
1 x 3125	6.25	4510

Circuit breaker A - LV side				
Busbar Ib	Trafo Feeder Ik	ABB SACE Circuit Breaker	Release	
[A]	[kA]		Size	Setting
91	2.2	T1B//T2N160	In=100	0.96
182	2.2	T1B/T2N160	In=100	0.96
144	3.6	T1B/T2N160	In=160	0.92
288	3.6	T1B/T2N160	In=160	0.92
180	4.5	T3N250	In=250	0.95/0.8
360	4.5	T3N250	In=250	0.95/0.8
231	5.7	T3N250	In=250	0.95/0.95
462	5.7	T3N250	In=250	0.95/0.95
289	7.2	T4N320	In=320	0.95
578	7.1	T4N320	In=320	0.95
361	8.9	T4N320	In=400	0.95
722	8.8	T5N400	In=400	0.95
455	11.2	T5N400	In=630	0.8
910	11.1	T5N630	In=630	0.8
577	14.2	T5N630	In=630/800	0.95/0.8
1154	14	T5N630/S6N800	In=630/800	0.95/0.8
722	17.7	T5N630/S6N800	In=800/1000	0.95/0.8
1444	17.5	S6N800/S7S1250	In=800/1000	0.95/0.8
909	22.3	S6N800/S7S1250	In=1000	0.95
1818	21.8	S7S1250/E1B1250	In=1000	0.95
2727	42.8	S7S1250/E1B1250	In=1000	0.95
1155	22.6	S7S1250/E1N1250	In=1250	0.95
2310	22.1	S7S1250/E1B1250	In=1250	0.95
3465	43.4	S7S1250/E1B1250	In=1250	0.95
1443	28.1	S7S1250/E1N1250	In=1600	0.95
2886	27.4	S7S1600/E2B1600	In=1600	0.95
4329	53.5	S7S1600/E2B1600	In=1600	0.95
1804	34.9	E2B2000	In=2000	0.95
3608	33.8	E2B2000	In=2000	0.95
5412	65.6	E3S2000	In=2000	0.95
2309	35.7	E3N2500	In=2500	0.95
4618	34.6	E3N2500	In=2500	0.95
6927	67	E3S2000	In=2500	0.95
2887	44.3	E3N3200	In=3200	0.95
5774	42.6	E3N3200	In=3200	0.95
8661	81.9	E3H3200	In=3200	0.95
3608	54.8	E4S4000	In=4000	1
4510	67.7	E6H5000	In=5000	1

Circuit breaker B (feeder circuit breaker)														
Busbar Ik	Feeder circuit breaker type and rated current													
[kA]	32A	63A	125A	160A	250A	400A	630A	800A	1250A	1600A	2000A	2500A	3200A	4000A
2.2	S250/S260													
4.4	S250/S260		T1B160											
3.6	S250/S260		T1B160											
7.2	S250/S260		T1B160											
4.5	S250/S260		T1B160											
8.8	S250/S260		T1B160											
5.7	S250/S260		T1B160											
11.4	T1B160				T3N250									
7.2	S250/S260		T1B160		T3N250									
14.2	T1B160				T3N250	T5N400								
8.9	S250/S260		T1B160		T3N250									
17.6	T1C160				T3N250	T5N400								
11.2	T1B160				T3N250	T5N400								
22.2	T1C160				T3N250	T5N400	T5N630							
14.2	T1B160				T3N250	T5N400								
28	T1N160				T3N250	T5N400	T5N630							
17.7	T1C160				T3N250	T5N400	T5N630							
35.9	T1N160				T3N250	T5N400	T5N630	S6N800						
22.3	T1C160				T3N250	T5N400	T5N630	S6N800/E1B800						
43.6	T2S160				T3S250	T5S400	T5S630	S6S800/E1N800	S7S1250/E1N1250					
64.2	T2H160				T4H250	T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600				
22.6	T1C160				T4N250	T5N400	T5N630	S6N800/E1B800						
44.3	T2S160				T3S250	T5S400	T5S630	S6S800/E1N800	S7S1250/E1N1250	S7S1600/E2N1600				
65	T2H160				T4H250	T5H400	T5H630	S6L800/E2N1250	S7L1250/E2N1250	S7L1600/E2N1600	E2N2000	E3N2500		
28.1	T1N160				T3N250	T5N400	T5N630	S6N800/E1B800	S7S1250/E1B1250					
54.8	T2H160				T4H250	T5H400	T5H400	S6H800/E2N1250	S7H1250/E2N1250	S7H1600/E2N1600	E2N2000			
80.2	T2L160				T4L250	T5L400	T5L630	S6L800/E3H1250	S7L1250/E3H1250	S7L1600/E3H1600	E3H2000	E3H2500	E3H3200	
34.9	T1N160				T3N250	T5N400	T5N630	S6N800/E1B800	S7S1250/E1B1250	S7S1600/E2B1600				
67.7	T2H160				T4H250	T5H400	T5H630	S6L800/E3H1250	S7L1250/E3S1250	S7L1600/E3S1600	E3S2000	E3S2500	E3S3200	
98.4	T4L160				T4L250	T5L400	T5L630	S6L800/E3H1250	S7L1250/E3H1250	S7L1600/E3H1600	E3H2000	E3H2500	E3H3200	E4H4000
35.7	T2N160				T3N250	T5N400	T5N630	S6N800/E1B800	S7S1250/E1B1250	S7S1600/E2B1600				
69.2	T2H160				T4H250	T5H400	T5H630	S6L800/E3S1250	S7L1250/E3S1250	S7L1600/E3S1600	E3S20200	E3S2500	E3S3200	E4S4000
100.6	T4L160				T4L250	T5L400	T5L630	E2L1250		S8V2000/E2L1600	E3L2000	E3L2500	E3L3200	E6V4000
44.3	T2S160				T3S250	T5S400	T5S630	S6S800/E1N800	S7S1250/E1N1250	S7S1600/E2N1600	E3N2000			
85.1	T4L160				T4L250	T5L400	T5L630	S6L800/E3H1250	S7L1250/E3H1250	S7L1600/E3H1600	E3H2000	E3H2500	E3H3200	E4H4000
122.8	T4L160				T4V250	T5V400	T5V630	E2L1250		E2L1600	E3L2000	E3L2500	E6V3200	E6V4000
54.8	T2H160				T4H250	T5H400	T5H630	S6H800/E2N1250	S7H1250/E2N1250	S7H1600/E2N1600	E3N2000	E3N2500	E3N3200	
67.7	T2H160				T4H250	T5H400	T5H630	S6L800/E3S1250	S7L1250/E3S1250	S7L1600/E3S1600	E3S2000	E3S2500	E3S3200	E4S4000

* Tables for protection and switching of 230V, 440V and 690V transformers also available on request

Notes

The tables refer to the previously specified conditions: the information for the selection of circuit breakers is supplied only with regard to the current in use and the prospective short-circuit current. For the correct selection, other factors such as selectivity, back-up protection, the decision to use limiting circuit breakers etc, must also be considered. Therefore, it is essential that the design engineers carry out precise checks.

It must also be noted that the short-circuit currents given are determined using the hypothesis of 750 MVA power upstream of the transformers, disregarding the impedances of the busbars or the connections to the circuit breakers.

Example:

Supposing the need to size breakers A1/A2/A3 on the LV side of three transformers of 630kVA 20/0.4 kV with u_k% equal to 4% and outgoing feeder circuit breakers B1/B2/B3 of 63-400-800 A:

From the table, corresponding to the row relevant to 3x630 kVA transformers, it can be read that:

Level A circuit breakers (LV side of transformer)

- Trafo I_r (909A) is the current that flows through the transformer circuit breakers
- Busbar I_b (2727A) is the maximum current that the transformers can supply
- Trafo Feeder I_k (42.8 kA) is the value of the short-circuit current to consider for the choice of the breaking capacity of each of the transformer circuit breakers
- S7S1250 or E1N1250 is the size of the transformer circuit breaker
- In (1000A) is the rated current of the transformer circuit breaker (electronic release chosen by the user)
- Setting (0.95) indicates the set value of function L of the electronic release

Level B circuit breakers (outgoing feeder)

- Busbar I_k (64.2 kA) is the short-circuit current due to the contribution of all three transformers
- Corresponding to 63A, read circuit breaker B1 Tmax T2H160
- Corresponding to 400 A read circuit breaker B2 Tmax T5H400
- Corresponding to 800 A read circuit breaker B3 Isomax S6L800 or E2N1250

The choice made does not take into account discrimination/back up requirements. Refer to ABB for further information.

Protection and switching of Transformers

General aspects

Transformers are used to achieve a change in the supply voltage, for both medium and low voltage supplies.

The choice of the protection devices must take into account transient insertion phenomena, during which the current may reach values higher than the rated full load current; the phenomenon decays in a few seconds.

The curve which represents these transient phenomena in the time-current diagram, termed 'inrush current I0' depends on the size of the transformer and can be evaluated with the following formula (the short-circuit power of the network is assumed to be equal to infinity).

$$I_{rg} = \frac{K \cdot I_{1r} \cdot e^{(-t/\tau)}}{\sqrt{2}}$$

Where:

K = ratio between the maximum peak inrush current value (I_0) and the rated current of the transformer (I_{1r}) : ($K = I_0 / I_{1r}$)

τ = time constant of the inrush current;

I_{1r} = rated current of the primary

t = time

The table below shows the indicative value for t and K parameters referred to rated power Sr for oil transformers.

Sr (kVA)	50	100	160	250	400	630	1000	1600	2000
$K = I_0/I_{1r}$	15	14	12	12	12	11	10	9	8
τ (s)	50	100	160	250	400	630	1000	1600	2000

For example, the inrush current for a 20/0.4kV of 400kVA transformer is equal to about 8 times the rated current; this transient phenomenon stops after a few tenths of a second.

The transformer protection devices must also guarantee that the transformer cannot operate above the point of maximum thermal overload under short-circuit conditions. This point is defined on the time-current diagram by the value of short-circuit current which can pass through the transformer and by a time equal to 2 s, as stated by Standard IEC 60076-5. The short-circuit current I_k for a fault with low impedance at the LV terminals of the transformer is calculated by using the following formula:

$$I_k = \frac{U_r}{\sqrt{3} \cdot (Z_{Net} + Z_t)} \qquad (1)$$

Where:

- U_r is the rated voltage of the transformer (V)
- Z_{Net} is the short-circuit impedance of the network (Ω)
- Z_t is the short circuit impedance of the transformer; from the rated power of the transformer S_r (VA) and the percentage short circuit voltage (u_k%) it is equal to:

$$Z_t = \frac{u_k\%}{100} \cdot \frac{U_r^2}{S_r} \quad (\Omega) \qquad (2)$$

Considering the upstream short-circuit power of the network to be infinite ($Z_{Net}=0$), (1) becomes:

$$I_k = \frac{U_r}{\sqrt{3} \cdot (Z_t)} = \frac{U_r}{\sqrt{3} \cdot \left(\frac{u_k\%}{100} \cdot \frac{U_r^2}{S_r} \right)} = \frac{100\, S_r}{\sqrt{3} \cdot u_k\% \cdot U_r} \quad (A) \qquad (3)$$

In Summary, for the correct protection of the transformer and to avoid unwanted trips, the curve of the protection device must be above the inrush current curve and below the overload point

Criteria for the selection of protection devices

For the protection at the LV side of MV/LV transformers, the selection of a circuit breaker shall take into account:

- The rated current at LV side of the protected transformer (this value is the reference value for the rated current of the circuit breaker and the setting of the protections);
- The maximum short circuit current at the point of installation (this value determines the minimum breaking capacity (I_{cu}/I_{cs}) of the protection devices).

MV/LV unit with single transformer

The rated current at the LV side of the transformer Ir is determined by the formula:

$$I_r = \frac{1000 \cdot S_r}{\sqrt{3} \cdot U_{r20}} \quad (A) \qquad (4)$$

Where:

- Sr is the rated power of the transformer (kVA)
- Ur_{20} is the rated LV no-load voltage of the transformer (V)

The full voltage three-phase short-circuit current (I_k) at the LV terminals of the transformer, can be expressed as (assuming that the short-circuit power of the network is infinite):

$$I_k = \frac{100 \cdot I_r}{u_k\%} \quad (A) \qquad (5)$$

Where:

u_k% is the short-circuit power of the transformer, in %,

The protection circuit breaker must have

$I_n \geq I_r$

$I_{cu}\ (I_{cs}) \geq I_k$

If the short-circuit power of the upstream network is not infinite and cable or busbar connections are present, it is possible to obtain a more precise value for I_k by using the formula (1), where Z_{Net} is the sum of the impedance of the network and of the impedance of the connection.

ML/LV substation with more than one transformer in parallel

For the calculation of the rated current of the transformer, the above applies (formula 4).

The breaking capacity of each protection circuit breaker on the LV side shall be higher than the short-circuit current equivalent to the short-circuit current of each equal transformer multiplied by the number of them minus one.

In a scheme with three transformers in parallel, with a fault downstream of a transformer circuit breaker, the short-circuit current that flows through the circuit breaker is equal to the contribution of a single transformer. In the case of a fault upstream of the same circuit breaker, the short-circuit current that flows is equal to the contribution of the other two transformers in parallel.

For correct dimensioning, a circuit breaker with a breaking capacity higher than twice the short-circuit current of one of the transformers must be chosen (assuming that all the transformers are equal and the loads are passive).

The circuit breakers positioned on the outgoing feeders shall have a breaking capacity higher than the sum of the short circuit currents of the three transformers, according to the hypothesis that the upstream network short-circuit power is 750MVA and the loads are passive.

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