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Short Circuit Rating Selection Criterion's for Circuit Breaker in PV Plants

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Abstract:

A Circuit Breaker is the main component in a switchgear which breaks the circuit & isolates the protected equipment from power system in case of a fault. However, while selecting the rating of a circuit breaker we normally specify only the continuous current rating & short time current rating of the breaker, which might not guarantee the suitability of the breaker for a given application.

In this paper the author intends to describe the other required parameters & methodology for calculation of these parameters which proves the suitability of the breaker for being used in the power system.

Introduction:

As we are already aware that a 3-phase short circuit fault is considered to be the most severe fault in any power system. When a 3-phase short circuit fault occurs, the fault current in the power system comprises of two components i.e. symmetrical AC component & the DC component of the fault current. Due to the presence of the DC component, the 3-phase short circuit fault current becomes asymmetrical in nature for the initial few cycles since the DC component of the fault current practically lasts only for a few cycles from the inception of the fault*. Also, the combination of the DC component & symmetrical AC component lead to a very high instantaneous value of the asymmetrical fault current when it reaches the first peak after the inception of the fault.

* Although the DC component of the fault current decays with time, it can never become zero theoretically. But in practical applications it lasts in the system only for 4-5 cycles from the instant of the inception of the fault & then disappears.

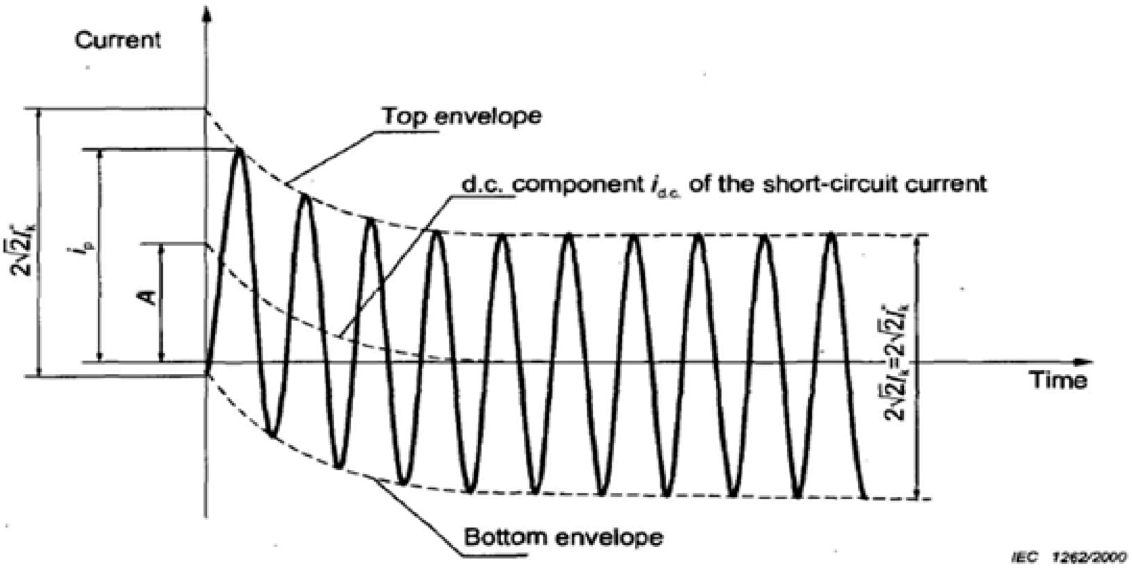
Required Parameters of A Circuit Breaker for its Interrupting Capacity:

Since the breaker is supposed to interrupt the fault current in order to minimize and/or prevent the damage of the protected equipment, the interrupter of the breaker is required to deal with the DC component of the fault current as well as the asymmetrical fault current & the peak short circuit current of the system. If the DC component of the fault current withstand capacity, overall asymmetrical fault current withstand capacity & the peak withstand current capacity of the breaker are not higher than the corresponding values of the 3 phase short circuit fault current of the power system in which the breaker is intended to be used, then the breaker shall not be able to safely interrupt the fault current in case of a 3 phase symmetrical short circuit fault in the power system. In such a scenario the breaker itself may even get burnt out, thereby putting the protected equipment as well as the other associated power system equipment in jeopardy. In certain cases, this may also lead to widespread blackout for a considerable amount of time causing generation losses. Therefore while selecting the breaker for any particular application, the user needs to ensure that the breaker is sufficiently rated to withstand the DC component of the fault current and the asymmetrical fault current & peak short circuit current of the system in addition to its rated continuous current rating & short time current ratings for a purposeful selection & operation of the breaker.

Note: - The purpose of this paper is to establish the parameters of the breaker which are associated with its rated interrupting capacity. Other fault ratings of a breaker like Short line fault current breaking capacity, Small fault current breaking capacity, out of phase fault current breaking capacity etc. are beyond the scope of this paper & hence not mentioned here.

Methodology for Calculation of the Required Parameters:

As stated above the DC component of the fault current practically lasts for 4-5 cycles in a power system from the inception of the fault i.e. it will be present in the fault current for 80-100 milli seconds for a 50Hz system. Figure 1 below depicts the presence of DC component in a 3-phase short circuit fault & its effect on the symmetrical component of the fault current to make the overall profile of the fault current asymmetrical in nature for the duration for which the DC component itself exists in the system. Once the DC component decays to zero, only the symmetrical component of the fault current exists based on which the user selects the short time current rating of the breaker. This symmetrical component is also called the steady state short circuit current of the system. Also, from the below figure it can be seen that the peak short circuit current is reached when the asymmetrical fault current attains its first peak after the inception of the fault.



I_k'' = initial symmetrical short-circuit current

i_p = peak short-circuit current

I_k = steady-state short-circuit current

$i_{d.c.}$ = d.c. component of short-circuit current

A = initial value of the d.c. component $i_{d.c.}$

Figure - 1

The DC component of the fault current & asymmetrical fault current vary with time & depend on the time instant at which they are measured and also on the symmetrical fault current of the system, system frequency & the value of X/R ratio of the system at the location of the fault. On the other hand, the peak short circuit current depends on the symmetrical fault current of the system & factor ‘k’ which is further dependent upon the value of X/R ratio of the system at the location of the fault. Hence the very first step to calculate the DC component of the fault current and the asymmetrical fault current & peak short circuit current of the system is to calculate the symmetrical fault current at the fault location.

The symmetrical short circuit current at any particular location of the power system can be calculated by the MVA method or by using equation No. 29 of IEC 60909-0 as mentioned in Eqn. A below.

$$I_k'' = c * U_n / (\sqrt{3} * Z_k) \qquad \text{................Eqn. A}$$

Where,

I_k'' = Initial symmetrical short circuit current in kA (same as steady state short circuit current or symmetrical short circuit current as per Figure 1)

U_n = Nominal system voltage in kV

Z_k = Short circuit impedance of the system up to the location of the fault in Ohm

c = Factor as per Table No. 1 of IEC 60909-0

The DC component of the fault current is calculated as per equation No. 64 of IEC 60909-0 as mentioned in Eqn. B below.

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$$i_{dc} = \sqrt{2} * I_k'' * e^{(-2\pi * f * t * R/X)}$$ ….…….…..Eqn. B

Where,

i_{dc} = DC component of the fault current in kA

f = System frequency in Hz

t = Time at which idc is calculated in seconds

R/X = Reciprocal of the X/R ratio of the system at the location of fault

The asymmetrical fault current (iasym in kA) is calculated as per Eqn. C below.

$$i_{asym} = I_k'' * \sqrt{(1 + 2 * (e^{(-2\pi * f * t * R/X)})^2)}$$ …..…….…..Eqn. C

The peak short circuit current is calculated as per equation No. 54 of IEC 60909-0 as mentioned in Eqn. D below.

$$i_p = k * \sqrt{2} * I_k''$$ ….…….…..Eqn. D

Where,

i_p = Peak short circuit current in kA

$k = 1.02 + 0.98 * e^{(-3 * R/X)}$ …..……….…..Eqn. E (as per equation No. 55 of IEC 60909-0)

Alternatively, the factor 'k' can also be found out from the Figure 2 below.

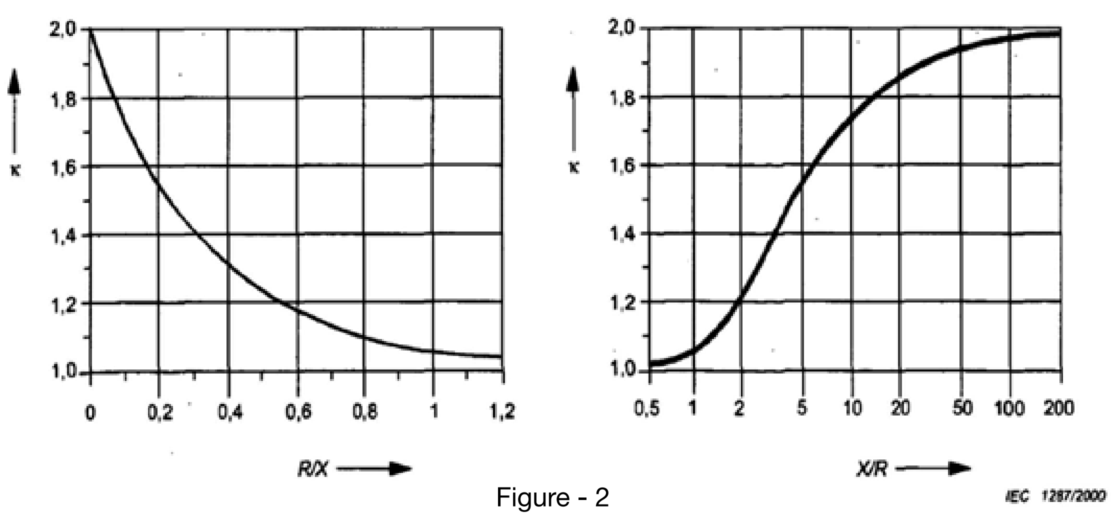


Figure - 2

The DC component of the fault current withstand capacity and the asymmetrical fault current withstand capacity of the breaker are dependent on the percentage DC component of the rated interrupting capacity of the breaker, which is further dependent on the rated breaking time of the circuit breaker. Therefore the DC component of the fault current & the asymmetrical fault current of the system are required to be calculated for a time duration equal to the rated breaking time of the circuit breaker to ensure these values are lower than the corresponding ratings of the breaker to guarantee successful fault interruption by the breaker in case of 3 phase short circuit fault in the system.

The percentage DC component of the rated interrupting capacity of the breaker (denoted as ‘p’) is dependent on the system X/R ratio or time constant & the rated breaking time of the circuit breaker as per Figure 9 of IEC 62271-100 which is depicted in Figure 3 below.

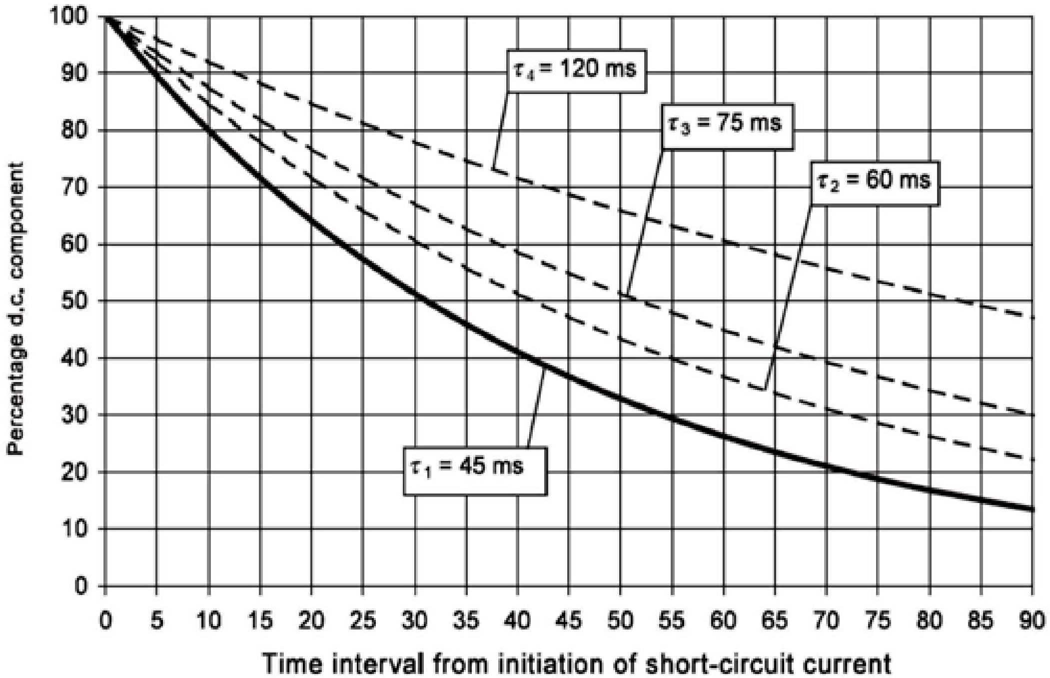


Figure - 3

Once the value of ‘p’ is determined from the above figure, the DC component of the fault current withstand capacity (I_{dc} in kA) of the breaker can be determined from the following equation

$$I_{dc} = \sqrt{2} * p * I_{st}$$ ……………Eqn. F

Where,

I_{st} = Short time current rating of the circuit breaker in kA

The asymmetrical fault current withstand capacity (I_{asym} in kA) of the breaker can be determined from the following equation

$$I_{asym} = \sqrt{(1+ 2 * p^2)} * I_{st}$$ ……………Eqn. G

The peak withstand current capacity of the breaker (I_p) is 2.5 times the short time current rating of the breaker for a 50 Hz system i.e

$$I_p = 2.5 * I_{st}$$ ……………Eqn. H

Example 1 (Hand Calculation):

Let us consider one typical Solar Power Plant application as shown in the Single Line Diagram below in Figure 4, wherein the 33kV switchgear is connected with the LV side of the 132/33kV power transformer via the 33kV outgoing feeder breaker & the RMUs located in PV field are connected with the 33kV SWGR via respective incoming feeder breaker. The 132kV side of the power transformer is connected to the power grid.

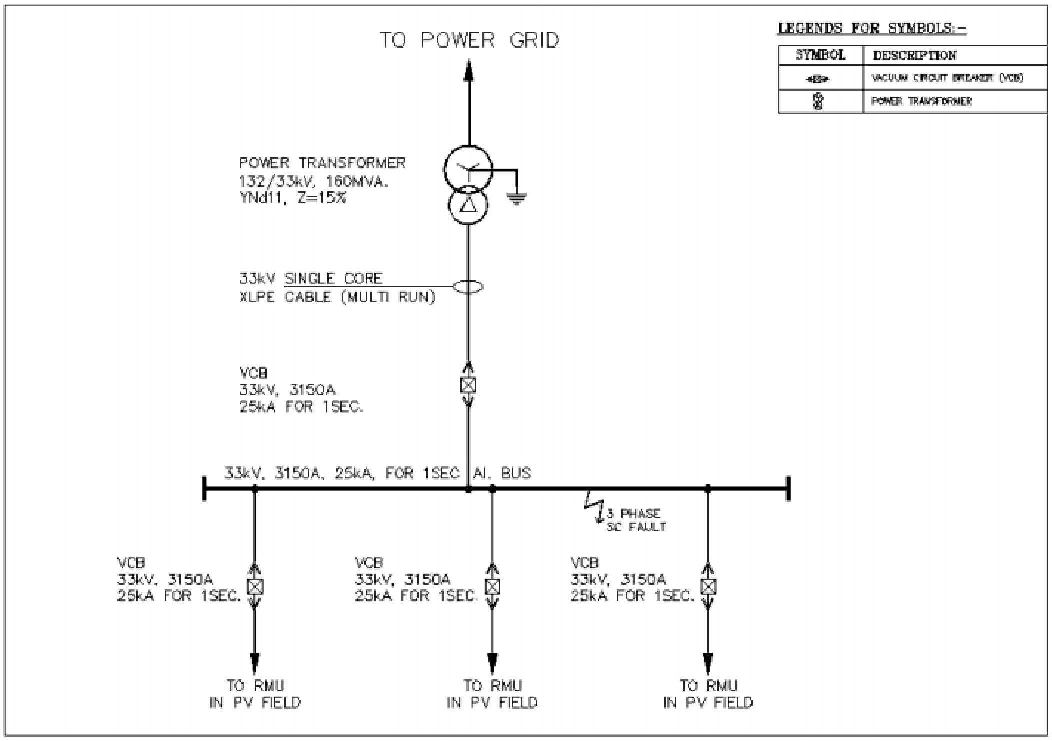


Figure - 4

If a 3-phase short circuit fault occurs on the bus bar of 33kV switchgear, the fault current contribution from the power grid shall flow through the power transformer, 33kV cable between the transformer & 33kV switchgear & 33kV outgoing feeder circuit breaker up to the bus bar of the switchgear. Therefore, the 33kV outgoing feeder breaker needs to interrupt the fault current to protect the 33kV switchgear bus bar. Hence in this example we will evaluate the adequacy of the values of I_{dc}, I_{asym} & I_p ratings of the breaker (as mentioned above in Eqn. F, G & H respectively) with the corresponding values of the 33kV SWGR bus bar fault current i.e. i_{dc}, i_{asym} & i_p respectively (as mentioned above in Eqn. B, C & D respectively).

The following assumptions are made for the purpose of this calculation.

Rated power output of the power transformer = 160MVA

Percentage impedance of the power transformer = 15%

X/R ratio of the system up to 33kV switchgear bus bar = 45

Rated breaking time of the breaker = 60ms

As mentioned earlier the very first step for the calculation of DC component of the fault current and the asymmetrical fault current & peak short circuit current of the system is to calculate the symmetrical fault current at the fault location, which can easily be calculated by MVA method. Therefore, for a fault on the 33kV switchgear bus bar, the value symmetrical or steady state fault current (I_k”) can be calculated as follows: -

I_k” = Power transformer rated MVA / (percentage impedance of transformer * √3 * Nominal system voltage at the fault location) = 160 / (0.15 * 1.732 * 33) kA = 18.66kA

Note:- For ease of calculation, the impedance of the 33kV cable between power transformer & 33kV switchgear is neglected in the above fault current calculation, which is also logical considering multiple runs of the cable for such high rating of the transformer & very small length. Also the above calculated fault current value shall be the maximum fault current that can be seen at the 33kV switchgear bus bar flowing from the grid side (considering no negative tolerance). Hence it is prudent to select the breaker ratings based on the above calculated fault current value as this will be the worst-case scenario.

Based on the above calculated value of Ik", we can easily select the required short time rating of the breaker as 25kA i.e. Ist = 25kA. But selecting a 25kA breaker may not be sufficient for this application as the breaker rating needs to pass the DC component of the fault current and asymmetrical fault current & peak short circuit current of the system also to guarantee the successful fault interruption by the breaker as explained earlier. All the following criterions are required to be fulfilled to prove the suitability of the 25kA rating breaker for this application.

$I_{dc} > i_{dc}$

$I_{asym} > i_{asym}$

$I_p > i_p$

Let's now calculate the values of the above parameters individually by using their respective equation.

As per Eqn. B, $i_{dc} = \sqrt{2} * 18.66 * e^{(-2\pi * 50 * 0.06 * (1/45))} = 17.36$ kA

As per Eqn. C, $i_{asym} = 18.66 * \sqrt{(1 + 2 * (e^{(-2\pi * 50 * 0.06 * (1/45))})^2)} = 25.49$ kA

As per Eqn. D, $i_p = 1.937 * \sqrt{2} * 18.66 = 51.12$ kA ($k = 1.02 + 0.98 * e^{(-3 * (1/45))} = 1.937$ as per Eqn. E)

For a system X/R ratio of 45 & rated breaking time of breaker equal to 60ms, the percentage DC component of the rated interrupting capacity of the breaker i.e. the value of 'p' shall be found out from Figure 3 above.

Hence p = 26.36% = 0.2636

As per Eqn. F, $I_{dc} = \sqrt{2} * 0.2636 * 25 =$ **9.32 kA**

As per Eqn. G, $I_{asym} = \sqrt{(1 + 2 * 0.2636^2)} * 25 =$ **26.68 kA**

As per Eqn. H, $I_p = 2.5 * 25 =$ **62.5 kA**

From the above calculations we can find that although the asymmetrical fault current withstand capacity & the peak withstand current capacity of the breaker are higher than the asymmetrical fault current & peak short circuit current of the system respectively, the selected breaker having rated short time withstand capacity of 25kA is not suitable for this application since the DC component of the fault current withstand capacity of the breaker is less than the DC component of the fault current of the system.

Example 2 (Software result):

For software-based results we may consider the same Single Line Diagram of Figure 4, model the same in ETAP & then run the Short Circuit Analysis. The results of the fault analysis in ETAP, which is attached herewith as an Annexure-1 also substantiate the fact that the breaker having short time current rating of 25kA might not be feasible for this application as it fails to meet some of the required criterions as mentioned above although the ETAP results give us the actual fault current value on the 33kV switchgear bus, which is less than the above calculated fault current.

Solution for the above problems:

It is needless to mention that the circuit breaker parameters are required to be adjusted to meet the above mentioned criterions since we cannot alter the system parameters & fault current values. Hence the various possible solutions in this regard are as follows: -

1 We can select a circuit breaker having a higher short time current withstand capacity which will also increase the DC component of the fault current withstand capacity of the breaker.

And/Or,

2 We can select a circuit breaker which has lesser rated breaking time, due to which the percentage DC component of the fault current withstand capacity of the breaker shall be higher to meet the system requirements.

And/Or,

3 We can ask the breaker manufacturer to consider higher X/R ratio value for the breaker design although the actual X/R ratio value of the system shall remain same since it is dependent upon the system parameters. In this case the breaker manufacturer shall consider higher X/R ratio to design the breaker interrupter, which will increase the value of the parameter ‘p’ for the same rated breaking time of the breaker, thereby achieving higher value of I_{dc} rating of the breaker with the same I_{st} rating of the breaker

For instance in Example-1, if we choose a circuit breaker having Ist rating of 40kA & rated breaking time of 40ms, then we achieve Idc = 23.25 kA, Iasym = 46.27 kA & Ip = 100 kA against idc = 19.96 kA, iasym = 27.33 kA & ip = 51.12 kA which means all criterions are met & the breaker is suitable for the application.

Alternatively if the circuit breaker is designed considering X/R ratio value of 75, then having a breaker even with rated breaking time of 75ms & Ist rating of 31.5kA will suffice all the requirements as we achieve Idc = 16.38 kA, Iasym = 35.51 kA & Ip = 78.75 kA against idc = 15.64 kA, iasym = 24.34 kA & ip = 51.12 kA which means the breaker is suitable for the application.

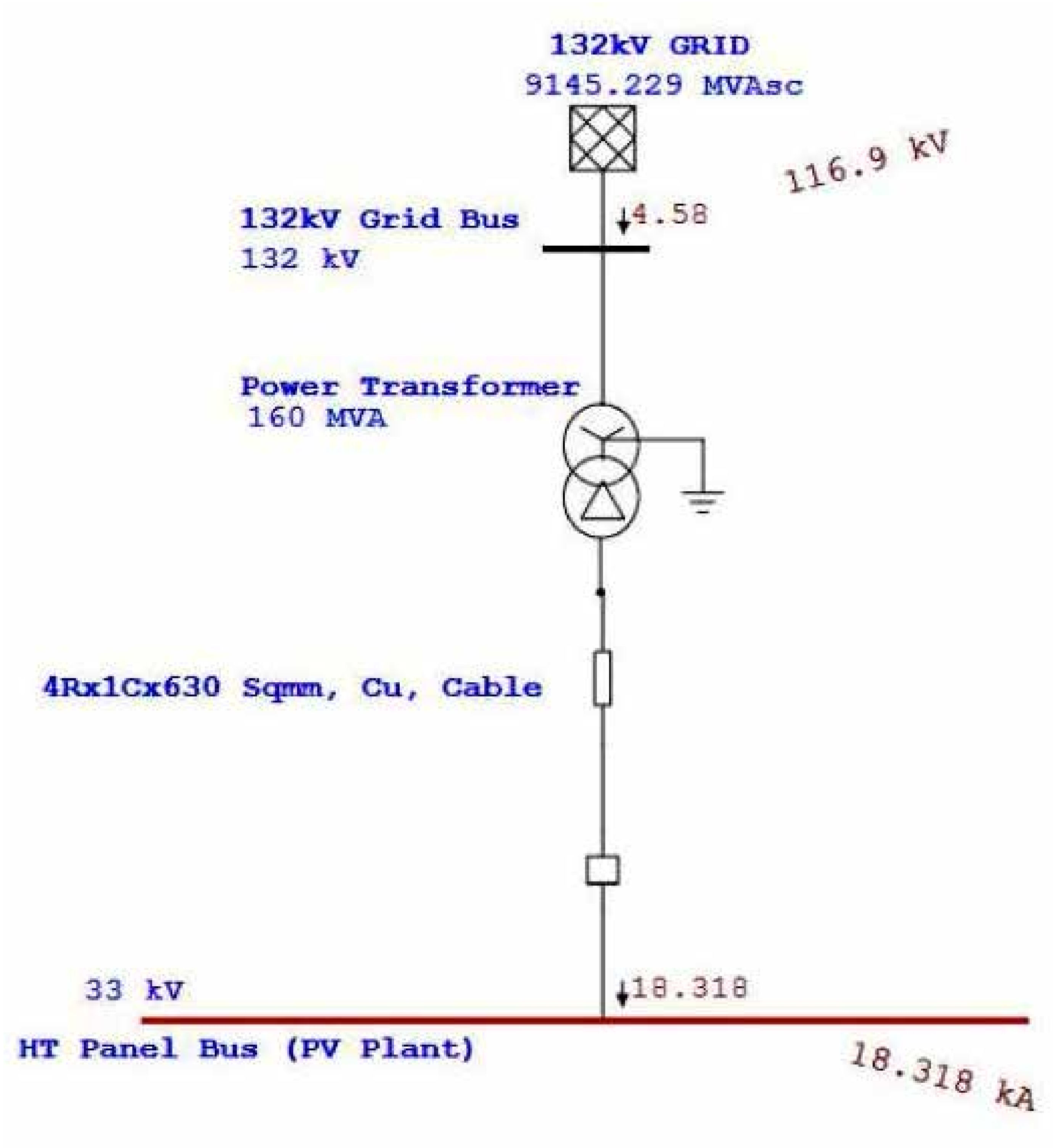
Conclusions:

From the above discussion & worked out examples it can be concluded that while selecting the fault current ratings of circuit breakers we need to crosscheck the rated short time withstand current, DC component of fault current withstand capacity, asymmetrical fault current withstand capacity & peak withstand current capacity of the breaker with the corresponding values of the system fault current to guarantee the suitability of the breaker for being used in the system. Defining only the rated short circuit withstand capacity of the breakeris not sufficient.

Reference Standard:

1. IEC 60909: Short circuit currents in 3 phase AC system: -
   Part 0 – Calculation of currents
   Part 1 – Factors for the calculation of short-circuit currents according to IEC 60909-0
2. IEC 62271: High-voltage switchgear and control gear: -
   Part 100 – High-voltage alternating-current circuit-breakers

Annexure-1


132kV GRID
9145.229 MVAsc
116.9 kV
132kV Grid Bus
132 kV
4.58
Power Transformer
160 MVA
4Rx1Cx630 Sqmm, Cu, Cable
33 kV
18.318
HT Panel Bus (PV Plant)
18.318 kA

SHORT-CIRCUIT REPORT

3-Phase fault at bus:	HT Panel Bus (PV Plant)	
Nominal kV	= 33.000	
Voltage c Factor	= 1.00	(User-Defined)
Peak Value	= 50.079	kA Method C
Steady State	= 18.318	kA rms

Contribution — Voltage & Initial Symmetrical Current (rms)

From Bus ID	To Bus ID	% V From Bus	kA Real	kA Imaginary	X/R Ratio	kA Magnitude
HT Panel Bus (PV Plant)	TotalBus1	0.00	0.432	-18.313	42.4	18.318
Bus1	HT Panel Bus (PV Plant)	0.54	0.432	-18.313	42.4	18.318
132kV Grid Bus	Bus1	88.55	0.432	-18.313	42.4	18.318

Breaking and DC Fault Current (kA)

Based on Total Bus Fault Current

TD (S)	Ib sym	Ib asym	Idc
0.01	18.313	30.237	24.057
0.02	18.313	28.890	22.340
0.03	18.313	27.676	20.746
0.04	18.313	26.584	19.266
0.05	18.313	25.605	17.891
0.06	18.313	24.730	16.614
0.07	18.313	23.950	15.428
0.08	18.313	23.256	14.327
0.09	18.313	22.640	13.305
0.10	18.313	22.096	12.356
0.15	18.313	20.208	8.533
0.20	18.313	19.243	5.893
0.25	18.313	18.765	4.070
0.30	18.313	18.532	2.811

Project:	ETAP	**Page:**
Location:	16.0.0C	**Date:** 20-04-2020
Contract:		**SN:** xxxx
Engineer:	**Study Case:** SCIEC	**Revision:** Base
Filename: SC analysis		**Config.:** Normal

SHORT-CIRCUIT REPORT

3-Phase fault Currents

Bus		Device		Device Capacity (kA)				Short-Circuit Current (kA)					
ID	kV	ID	Type	Making Peak	Ib sym	Ib sym	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
HT Panel Bus (PV Plant)	33.000	HT Panel Bus (PV Plant)	Bus					18.318	50.079				18.318
	33.000	3150A, VCB	CB	62.500	25.000	26.681	9.320	18.318	50.079	18.318	24.730	16.614*	

ip is calculated using method C

Ib does not include decay of non-terminal faulted induction motors

Ik is the maximum steady state fault current

Idc is based on X/R from Method C and Ib as specified above

LV CB duty determined based on service rating.

Maximum through current is used for device duty.

* Indicates a device with calculated duty exceeding the device capability.

# Indicates a device with calculated duty exceeding the device marginal limit. (95 % times device capability)

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