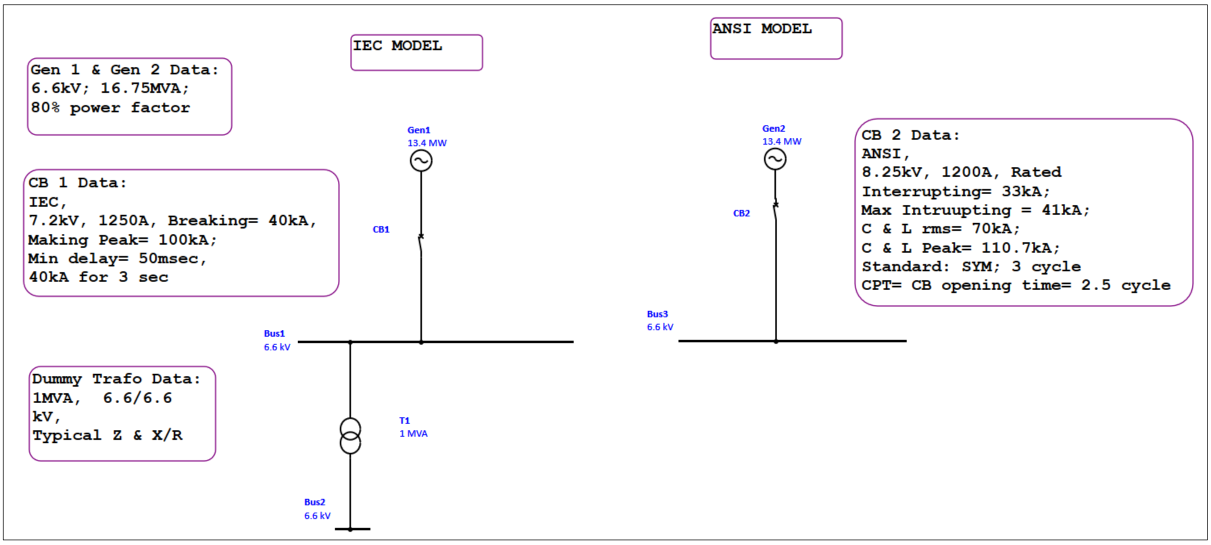
IEC IEEE & ETAP Generator Terminal Fault Calculation and comparison

Purpose and Description:

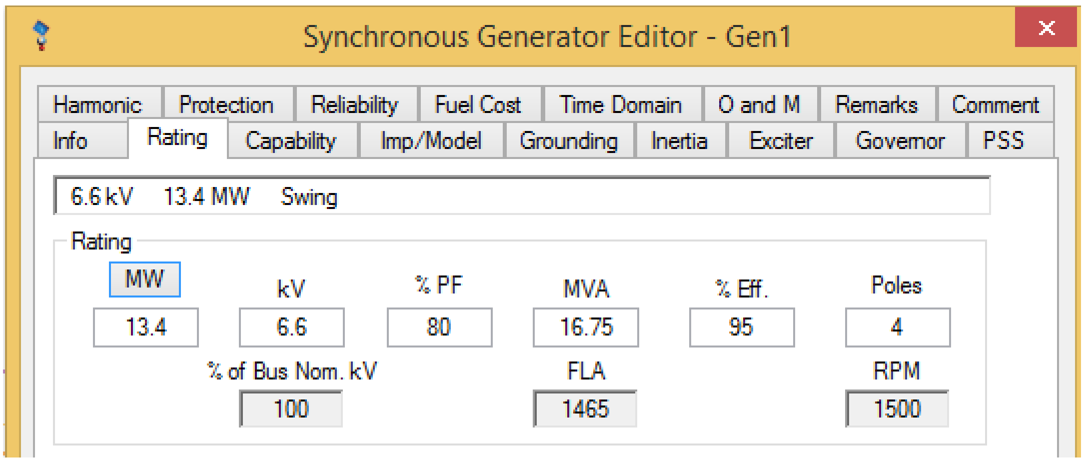
The purpose of this exercise is to study the fault current contribution from generator by using IEC-60909 and ANSI/IEEE standard using excel and ETAP.
The datasheet of generator is attached at the end of this exercise.

Case 1: Calculation of fault current contribution at generator terminal using IEC standard

1. This exercise involves creating the below shown SLD and entering the corresponding data into the etap. The detailed modelling is shown in subsequent steps.



2. Enter the generator rating and reactance values for Gen1 as shown below.



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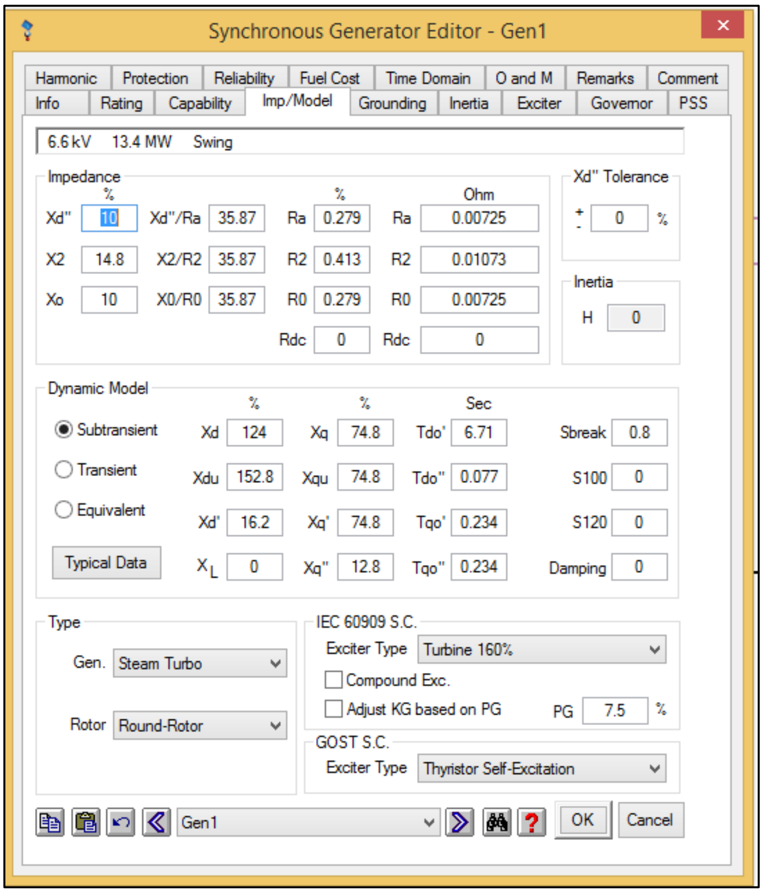
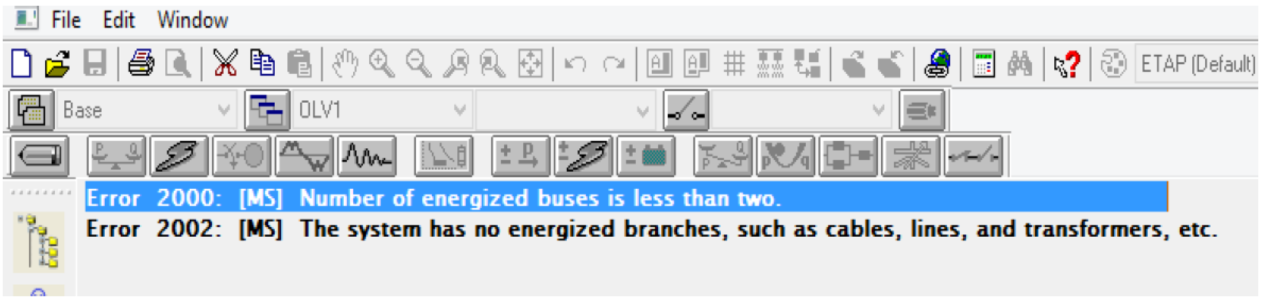


3. Add the dummy transformer. Otherwise etap may show you the below error.



4. Add circuit breaker CB-1 and entered the rating as below.

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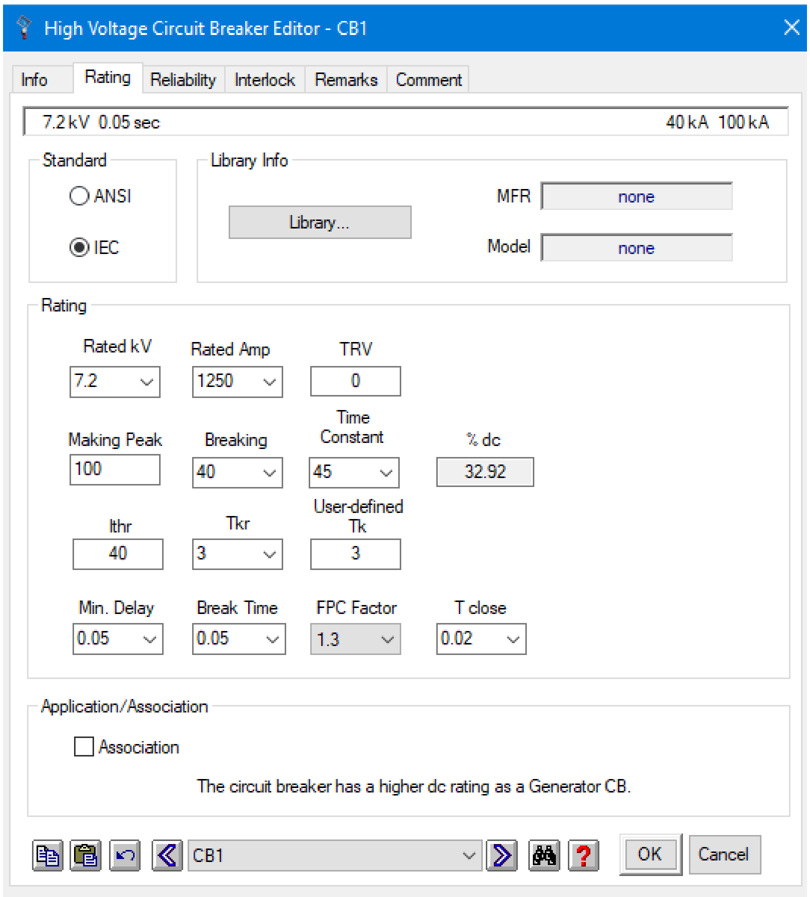

5. Go to SC module, make a new study case as '**Test_IEC**'.
6. Open the study case **'Test_IEC'**, go to the standard page. Choose standard as IEC. Also select user-defined c factor and make it equal to 1 as shown in below image.

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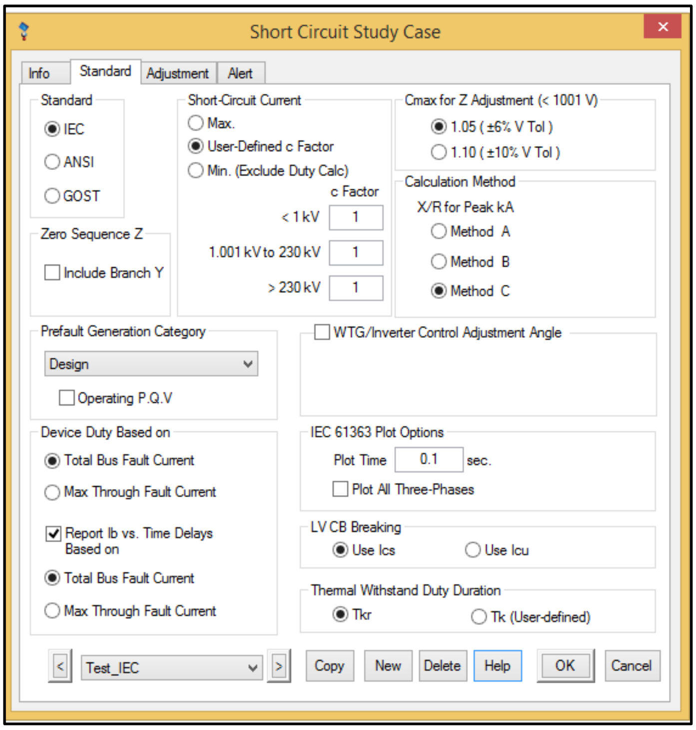

7. Go to SC module, select bus1, right click on it and make a fault on bus1.
8. Run the 3-phase device duty calculation.
9. Select the Report Manager option (present on the right hand side of the screen in SC Module), select the Summary tab and the PDF option and generate the report. Etap will shows the following results:

Short-Circuit Summary Report

3-Phase Fault Currents

Bus		Device		Device Capacity (kA)				Short-Circuit Current (kA)					
ID	kV	ID	Type	Making Peak	Ib sym	Ib asym	Idc	I"k	ip	Ib sym	Ib asym	Idc	Ik
Bus1	6.600	Bus1	Bus					14.114	36.216				3.763
	6.600	CB1	CB	100.000	40.000	44.122	18.622	14.114	36.216	10.421	16.570	12.882	

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.
Total 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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Excel calculation of short circuit currents by IEC standard:

Input require:

Generator Data: (The datasheet of generator is attached at the end of this exercise)

Un	6.6	kV	Nominal bus	*ETAP input required*
Urg	6.6	kV	Rating for Gen	*ETAP input required*
MVA	16.75	MVA		*ETAP input required*
Frequency	50	Hz		*ETAP input required*
IrG	1.465	kA		*Evaluated in ETAP*
pf	0.8			*ETAP input required*
Exciter Type	160	%	series 2	*ETAP input required*
cylindrical round rotor	For steady state short circuit current calculation			
Xd	124	%	*ETAP input required*	
Xd"	10	%	*ETAP input required*	
X2	14.8	%	*ETAP input required*	
Ta	0.169	sec	*ETAP input required*	
Ra	0.2788	%	*ETAP input required from vendor data* ***OR*** *Derived From Ta of generator, where 2.pi.f.Ta = X2/Ra*	

A. Calculation of Ik" including correction factor for Xd"

C	1		*User defined*
Cmax	1.1		*As per* ***Table-1(Voltage factor c)*** *of IEC 60909-0-2001 page No.41*
KG	1.03774		***KG=(Un/Urg)*(Cmax/(1+Xd"pu*sin(phi))*** *as perIEC 60909-2001 eqn. no. 18 of page 61*
ZGk	0.10381	pu	***ZGk=KG.ZG = KGxsqrt(Ra^2+Xd"^2)*** *as perIEC 60909-2001 eqn. no. 17 of page 61*
ZGk	0.26998	Ohm	Where, ZGk in ohm = ZGK pu *Zbase'
			& Z base= kV^2 / MVA= 2.6006 ohm
Ik"=	***14.115***	***kA rms***	***Ik" =C.UN/Sqrt(3)/ZGk*** *as per eqn. no.29 of page no.83 of IEC 60909-0 2001*

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B. Calculation of peak SC Ip

Rgf	0.07 * Xd"		***This value is set inside ETAP software (no user can change this) as per page 63 of IEC 60909-0 2001***
Rgf/Xd" =	0.07		*For <100 MVA*
K =	1.814		*Factor is **K =1.02+0.98*exp(-3.Rgf/Xd")** as per equation 55 of page no. 101 IEC 60909-0 2001*
Ip=	***36.217***	***kA p inst***	***ip = sqrt(2).K.Ik"** as per eqn no. 54 of page no.101 of IEC 60909-0-2001*

C. Calculation of idc at CB opening time

TO t opening =0.05 sec=2.5 cycles

Calc of Tau for idc

Xd"/Ra = 35.8736

Ra/Xd" = 0.02788

Idc(OTms)=12.88 kA rms

*idc=sqrt(2)*Ik"*exp(-2*pi*f*t*Ra/Xd") as per eqn no. 64 of page no.107 of IEC 60909-0-2001*

D. **Calculation of Ib=Iac decay at opening time and assessment of Asymmetrical break ibasymm kA**

μ = 0.738535

μ = 0.71+0.51*e^-0.30*Igk"/IrG) as per eqn 70 of page 109 of IEC 60909-0 2001

Ib =Ibac(OTms)= 10.421 kA rms

Ib = μ*Ik" as per eqn 69, page 109 of IEC 60909-0 2001

E. Calculation of Ibasym asymmetrical break at selected OT

Ibasym (OTms)= 16.57 kA rms

Ibasym(OTms) = sqrt(Ibac(OT) ^2+Idc(OTms)^2

F. Calculation of Ik =steady state SC kA

IkG"/IrG= 9.63262

Xd =1.24

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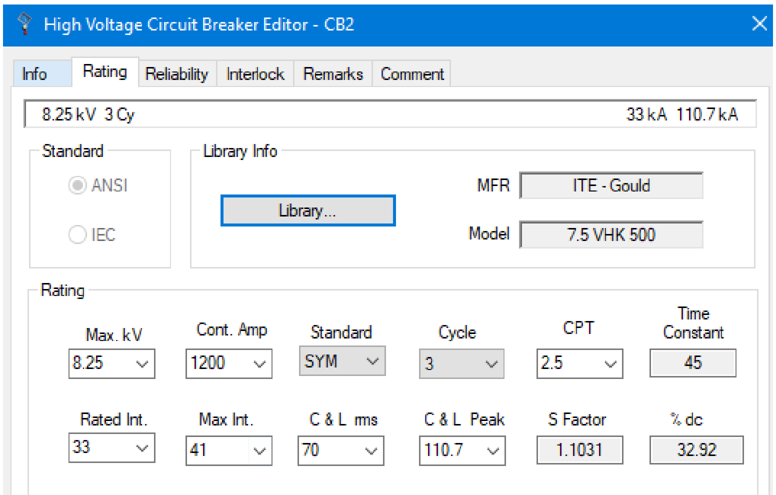
λmax= 2.568 as per Fig. 18a for series 2 on page 119 of IEC 60909-0 2001

Ikmax= 3.763 kA rms

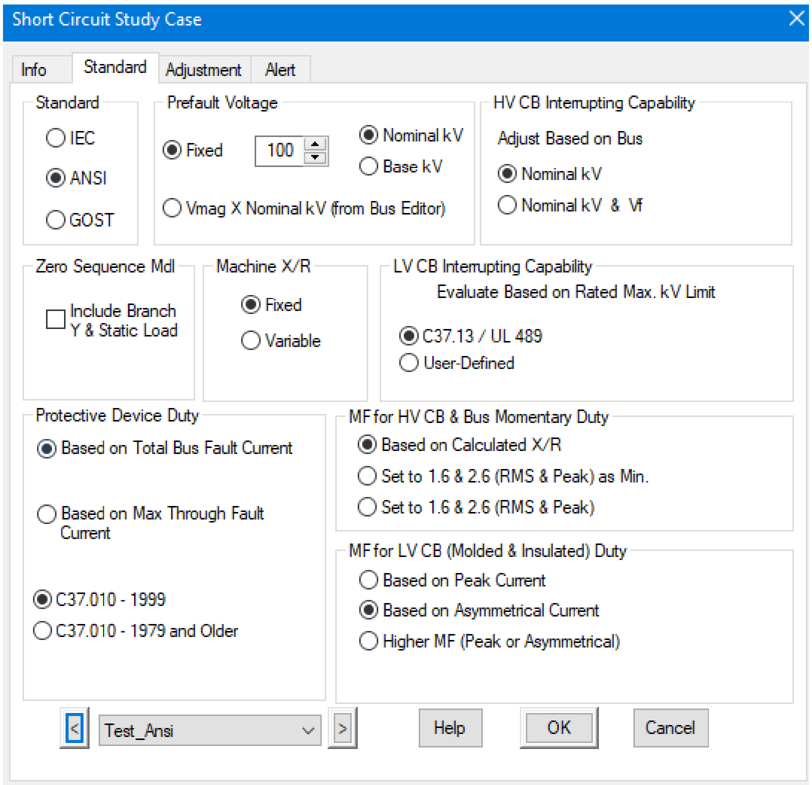
Summary		ib at	2.5	cycle	
Excel					
Ik"	ip	ibsym	ibasym	idc	ik
kA rms	kA p inst.	kA rms	kA rms	kA rms	kA rms
14.115	36.217	10.421	16.570	12.883	3.763
ETAP					
Ik"	ip	ibsym	ibasym	idc	ik
kA rms	kA p inst.	kA rms	kA rms	kA rms	kA rms
6.674	17.124	5.087	8.428	6.719	2.079

Case 2: Calculation of fault current by ANSI standard

1. Copy the generator, CB and bus system.
2. In CB2 rating page make the standard as ANSI type. Entered the ratings in CB2 as shown below.
   Note that the standard chosen is SYM now.



3. Go to SC module, make a new study case as **'Test_ANSI'.**
4. Open the study case **'Test_ANSI'**, go to the standard page. Choose standard as ANSI.



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5. Now, make a fault on bus3 and run the 3-phase device duty calculation.
6. Etap will shows the following results:

Momentary Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

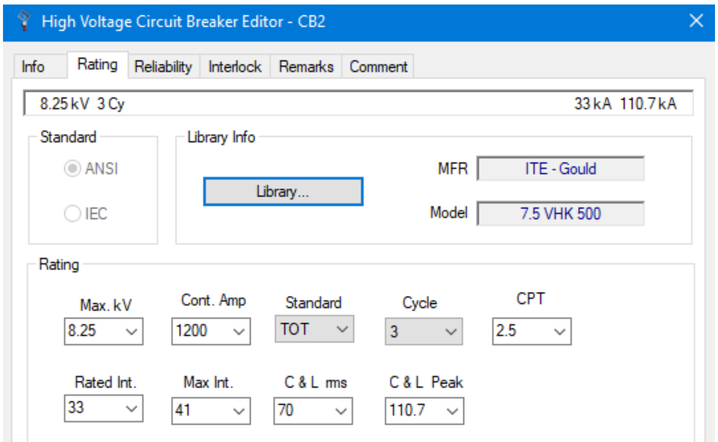
Bus		Device		Momentary Duty					Device Capability		
ID	kV	ID	Type	Symm. kA rms	X/R Ratio	M.F.	Asymm. kA rms	Asymm. kA Peak	Symm. kA rms	Asymm. kA rms	Asymm. kA Peak
Bus3	6.600	Bus3	Bus	14.647	35.9	1.637	23.972	39.690			
	6.600	CB2	3 cy Sym CB	14.647	35.9	1.637	23.972	39.690		70.000	110.700

Interrupting Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device		Interrupting Duty					Device Capability			
ID	kV	ID	Type	CPT (Cy)	Symm. kA rms	X/R Ratio	M.F.	Adj. Sym. kA rms	kV	Test PF	Rated Int.	Adjusted Int.
Bus3	6.600	CB2	3 cy Sym CB	2.5	14.647	35.9	1.061	15.539	8.250		33.000	41.000

7. Now change the CB2 Standard to TOT.



8. Re-run the ANSI SC studies. And observe the fault currents.

Momentary Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device		Momentary Duty					Device Capability		
ID	kV	ID	Type	Symm. kA rms	X/R Ratio	M.F.	Asymm. kA rms	Asymm. kA Peak	Symm. kA rms	Asymm. kA rms	Asymm. kA Peak
Bus3	6.600	Bus3	Bus	14.647	35.9	1.637	23.972	39.690			
	6.600	CB2	3 cy Tot CB	14.647	35.9	1.637	23.972	39.690		70.000	110.700

Interrupting Duty Summary Report

3-Phase Fault Currents: (Prefault Voltage = 100 % of the Bus Nominal Voltage)

Bus		Device		Interrupting Duty					Device Capability			
ID	kV	ID	Type	CPT (Cy)	Symm. kA rms	X/R Ratio	M.F.	Adj. Sym. kA rms	kV	Test PF	Rated Int.	Adjusted Int.
Bus3	6.600	CB2	3 cy Tot CB	2.5	14.647	35.9	1.170	17.141	8.250		33.000	41.000

Excel calculation of short circuit currents by ANSI standard:

Input require:

Generator Data

Un	6.6	kV	Nominal bus	*ETAP input required*
Urg	6.6	kV	Rating for Gen	*ETAP input required*
MVA	16.75	MVA		*ETAP input required*
Frequency	50	Hz		*ETAP input required*
IrG	1.465	kA		*Evaluated in ETAP*
pf	0.8			*ETAP input required*
Exciter Type	160	%	series 2	*ETAP input required*
cylindrical round rotor	For steady state short circuit current calculation			
Xd	124	%	*ETAP input required*	
Xd"	10	%	*ETAP input required*	
X2	14.8	%	*ETAP input required*	
Ta	0.169	sec	*ETAP input required*	
Ra	0.2788	%	*ETAP input required from vendor data **OR** Derived From Ta of generator, where 2.pi.f.Ta = X2/Ra*	

NACD Calculation

NACD= Iremote/Itotal = 0;
(If all faults are local to generator then NACD =0)

A. Calculation of Imom,rms,symm(momentory short ckt current for 0.5 cycle network fault)=Ik" as per IEC 60909-0 2001

V pre-fault	1	x Nominal KV	*User defined*
Zeq 0.5 cy	0.100003	pu	***Zeq=Sqrt(Ra^2+Xd"^2) . Generator reactance for 1/2 cy = Xd"***
Zeq 0.5 cy	0.260160	Ohm	Zbase= 7.22 ohm; Zeq in ohm = Zeq pu*Zbase'
Imom,rms,symm=	***14.647***	***kA rms***	***Imom,rms,symm=Vpre-fault/Sqrt(3)/Zeq0.5cy . This is Ik" of IEC 60909***

B. Calculation of momentary peak SC C Ip

MFm for 0.5 cy	1.637		***MFm=SQRT(1+(2EXP(-(2*PI()/(Xd'/Ra)))-momentory multiplying factor for asymmetric fault current***
MFp for 0.5 cy	2.710		***MFp=SQRT(2)*(1+(EXP(-(PI()/(Xd'/Ra)))-momentory multiplying factor for peak fault***
MFr for 0.5 cy	1.722		*Not required for close to generator terminal fault*
Imom,peak=	***39.692***	***kA p inst***	***Imom,peak= MFp*Imom,rms,symm***
Imom,rms,asymm=	***23.973***	***kA rms***	***Imom,peak= MFp*Imom,rms,symm***

C. I int rms sym (1.5 to 4 cycle fault network calc)

t =Contact Part Time	2.5	cycle	For 3 cycle CB
S	1.1031		S factor for AC HV CB rated on symmetrical current basis based on HVCB tested for Dc decay of 45 msec
Zeq 1.5 to 4 cy	0.1000388	pu	***Zeq=Sqrt(Ra^2+Xd"^2) . Generator reactance for 1.5 to 4 cy = Xd" as per IEEE***
Zeq 1.5 to 4 cy	0.260160	Ohm	Zbase= 7.22 ohm; Zeq in ohm = Zeq pu*Zbase'
I int rms sym	***14.647***	***kA rms***	***I int,rms,symm=Vpre-fault/Sqrt(3)/Zeq1.5 to 4cy .***
Xd"/Ra =	35.8735		
MFr for 1.5 to 4 cy	1.3539		r=Remote contribution (MFr remote mult factor). As per IEEE Graph or etap table *MFr can be calculated as* ***MFr=sqrt(1+2*exp(-(4*pi()*t/(Xd"Ra)))****for Contact Part Time in cycles*
MFl for 1.5 to 4 cy	1.17		l- Local contribution(MFl=local mult factor). As per IEEE Graph or etap table

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AMFi	1.17		Actual multiplying factor *AMFi can be calculated as **AMFi=MFI+NACD(MFr-MFI)** for Contact Part Time = 2.5 cycles*
Net AMF	1.06064		*Net **AMFi=AMFi/S***
Iint,rms,adj (sym current basis)	***15.5355***	***kA rms***	*Net AMF*Int,rms,symm if HVCB is based on Symmetrical Current Basis* ***= (I int rms sym * AMFi) / S***

Total Current = Asymm break

Iint,rms,adj (Total current basis)	***17.1372***	***kA rms***	*AMFi*Int,rms,symm if HVCB is based on TOTAL Current Basis* ***= I int rms sym * AMFi***

	0.5 cyc momentary fault				**1.5 cyc to 4 cyc momentary fault**		
	Imom,rms,symm=	**Imom,peak =**	**Imom,rms,asymm=**		**I int rms sym**	**Iint,rms ,adj (sym current basis)**	**Iint,rms,adj (Total current basis)**
	Ik"	**ip**					**Ib asym**
	kA	**kA**	**kA**		**kA**	**kA**	**kA**
	rms	**peak**	**rms**		**rms**	**rms**	**rms**
EXCEL ANSI IEEE	**14.647**	**39.692**	**23.973**		**14.647**	**15.5355**	**17.1372**
ETAP ANSI IEEE	**6.814**	**18.639**	**11.29**		**6.814**	**7.66**	**8.449**

- **Comparison between IEC and ANSI standard Short circuit results:**

C factor in IEC OR Pre fault voltage in IEEE set at			1	pu of nominal Voltage
CB opening time	2.5	cycle	or	
	0.05	ms at	50	Hz

Calculation outputs	Ik" or Imom,sym rms	ip or Imom, peak	Ib symm or Int,sym rms	ib asymm or Iint,rms,adj (Total current basis)
	kA rms	kA preak	kA rms	kA rms
IEC Excel	14.115	36.217	10.421	16.570
IEEE Excel	14.647	39.692	14.647	17.137
IEC ETAP	6.674	17.124	5.087	8.428
IEEE ETAP	6.814	18.639	6.814	8.449

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ELECTRICAL DATA

N.B. Electrical Performance Figures are subject to tolerances.
(Reactances ±15%. Time constants and pu. resistances ±30% and Ohmic resistances ±10 %.)

Rated Output KVA	Rated Output KW	Rating Temp. ^0C	PF(cosφ)	Poles	Phases	Voltage Volts	Current Amps	Frequency Hz	Speed RPM
16750	13400	15	0.8	4	3	6600	1465	50	1500
16250	13000	20	0.8				1422		

Stator Winding Configuration :-	Star	Governing Standard :-	IEC 60034
Ambient Temperature Range :-	-20 to 40°C	Max. Operating Altitude :-	1000m
Total Temperature Rises to Class :-	B	Insulation Class :-	F
Max. Stator Operating Temp. ^0C	125°C	Max. Field Operating Temp. ^0C	120°C
Short circuit ratio SCR	0.809 ± 10%	Inertia constant H (MJ/MVA) Generator only	0.81
Maximum Voltage Distortion (%)	THD < 5% (No load)	Telephone Influence Factor	<100 Balanced

Parameters are based on 16750kVA	Saturated	Unsaturated
Synchronous Reactance (D-Axis) Xd (pu) :-	1.24	1.528
Transient Reactance (D-Axis) X'd (pu) :-	0.162	0.207
Sub-transient Reactance (D-Axis) X"d (pu):-	0.100	0.129
Synchronous Reactance (Q-Axis) Xq (pu):-		0.748
Transient Reactance (Q-Axis) X'q (pu):-		0.748
Sub-transient Reactance (Q-Axis) X"q (pu):-	0.128	0.165
Stator Winding Leakage Reactance X1 (pu):-		0.060
Negative phase sequence reactance X2 (pu):-		0.148
Potier reactance Xpot (pu):-		0.173
Stator winding dc resistance Ra (pu):- 95 C		0.00343
Positive phase sequence resistance R1 (pu):- 95 C		0.00522
Negative phase sequence resistance R2 (pu):- 95 C		0.017
Zero phase sequence reactance X0 (pu):-		0.022
Zero phase sequence resistance R0 (pu):- 95 C		0.00604
OC transient field time constant T'do (s) :-		6.71
SC transient field time constant T'd (s) :-	0.708	0.912
OC sub-transient time constant DA T"do (s) :-		0.077
SC sub-transient time constant DA T"d (s) :-	0.039	0.048
OC sub-transient time constant QA T"qo (s) :-		0.234
SC sub-transient time constant QA T"q (s) :-		0.052
Armature dc time constant Ta (s) :-	0.111	0.169

Negative phase sequence continuous (I_2 withstand) (%)	8	Negative phase sequence heating I_2^2t (s)	20
Machine Cooling Time Constant (secs) for Neg. Seq. Relay T reset	3125	Winding Capacitance per phase (μF)	0.193
Saturation factor S (1.0)	1.24	Saturation factor S (1.2)	3.70
Maximum kVAr available at 0 pf Under-excited (pu)	0.59	Maximum kVAr available at 0 pf Over-excited (pu)	0.64
Maximum Terminal Voltage under Field Forcing (Fault Condition Open Circuit)			8625

IEC tolerance applies	100% Load (pu)	75% Load	50% Load	25% Load
Gen'r. Efficiency at rated PF (pu)	0.9812	0.9799	0.9752	0.9580
Gen'r. Total Losses (KW)	257.4	206.7	170.2	146.9
Max Volt Dip % - Load Acceptance	13.3	10.3	8.0	4.2
Max Volt Rise % - Load Shed	15.0	11.3	8.3	4.2