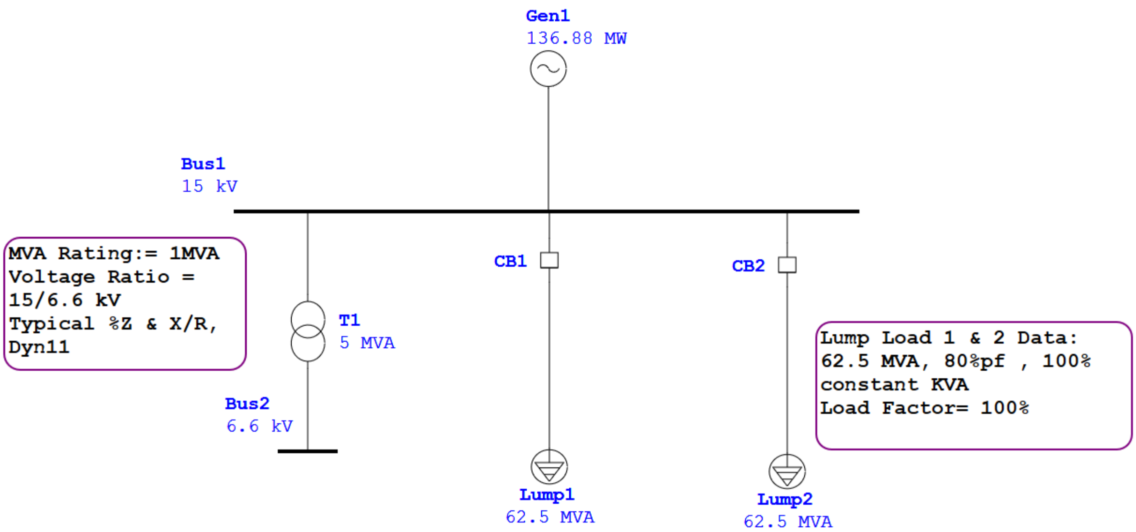
Generator Modelling

Purpose and Description

The purpose of this exercise is to model the generator as per inputs provided in vendor datasheet.

Procedure:

1. Create a new project with name ‘Gen Modelling’.
2. Drag and drop the generator, bus, lump load, circuit breaker, transformer on the OLV. Connect these elements and enter the data as shown below.



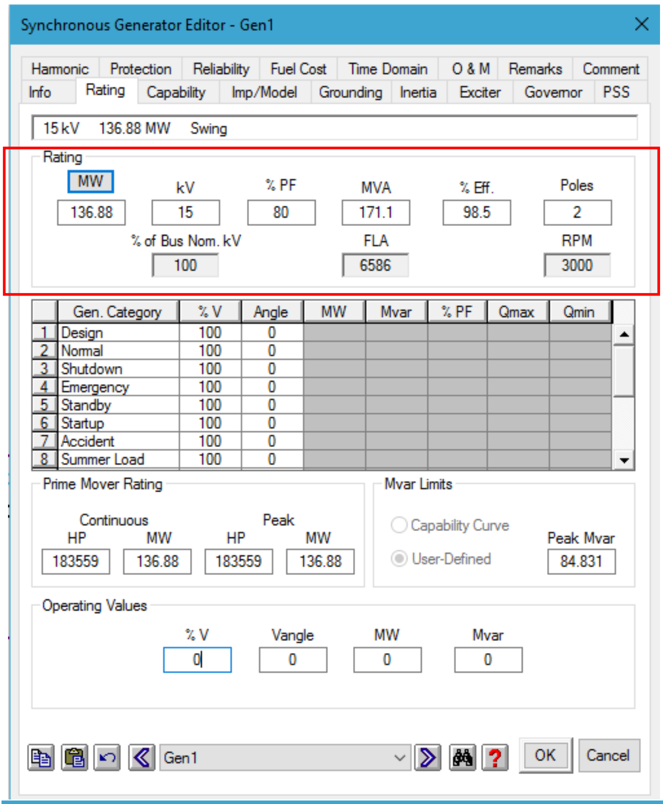
3. Details of Annexures:

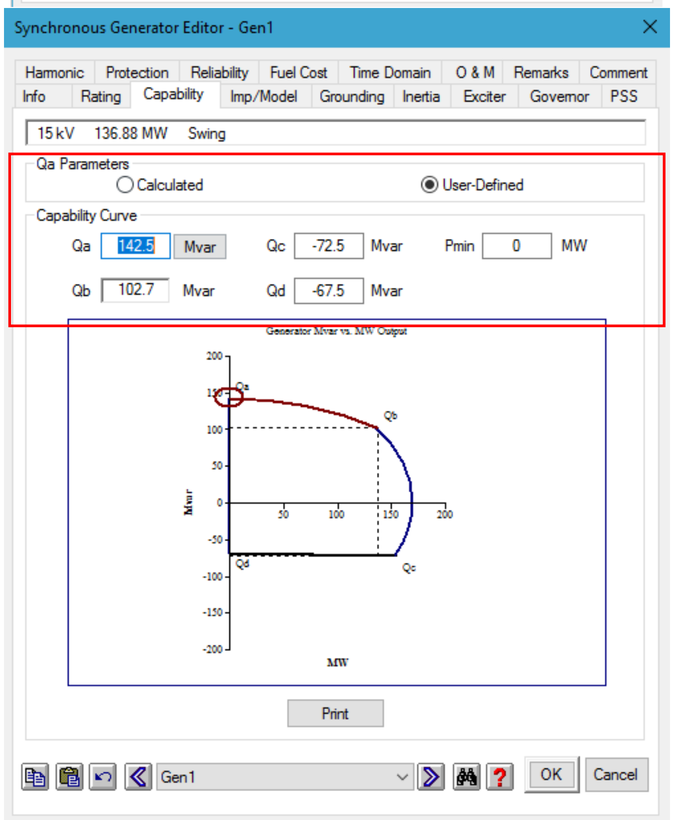
Annex-1 :Details of Generator model testing in ETAP
Annex-2 :Summary of data used in modelling of Generator
Annex-3 :Actual Vendor Datasheet

Sheet 3.1: Generator Vendor Datasheet
Sheet 3.2: Generator Vendor Datasheet
Sheet 3.3: Variation of Generator Output with Coolant Temp. Curve
Sheet 3.4: Generator Capability Diagram
Sheet 3.5: Variation of Generator Efficiency with Load
Sheet 3.6: Generator Open Circuit & Short Circuit Characteristics
Sheet 3.7: Permissible Duration of Generator Armature Current
Sheet 3.8: Permissible Duration of Negative Sequence Current
Sheet 3.9: Inertia Data of Generator & Turbine
Sheet 3.10: Exciter Vendor Datasheet
Sheet 3.11: Exciter Vendor Datasheet
Sheet 3.12: Evaluation Sheet for Capability Curve points
Sheet 3.13: Evaluation Sheet for S_{break}, S_{100} & S_{120} Calculation
Sheet 3.14: Evaluation Sheet for Generator Efficiency calculation

Generator Modelling

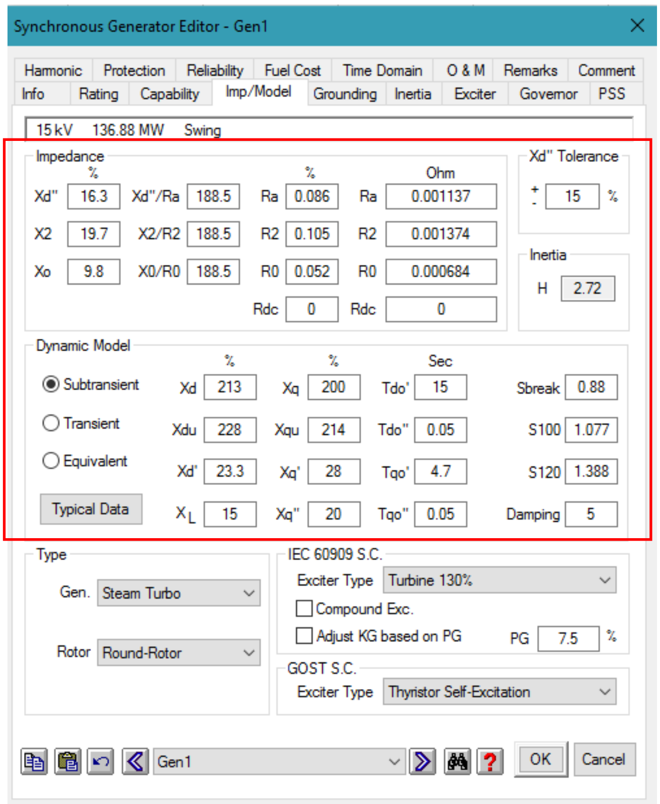
4. Enter inputs for generator referring to ‘Annex2- Summary Of Data’ which has data extracted from ‘Annex3- Actual Vendor Datasheet’ as shown below:





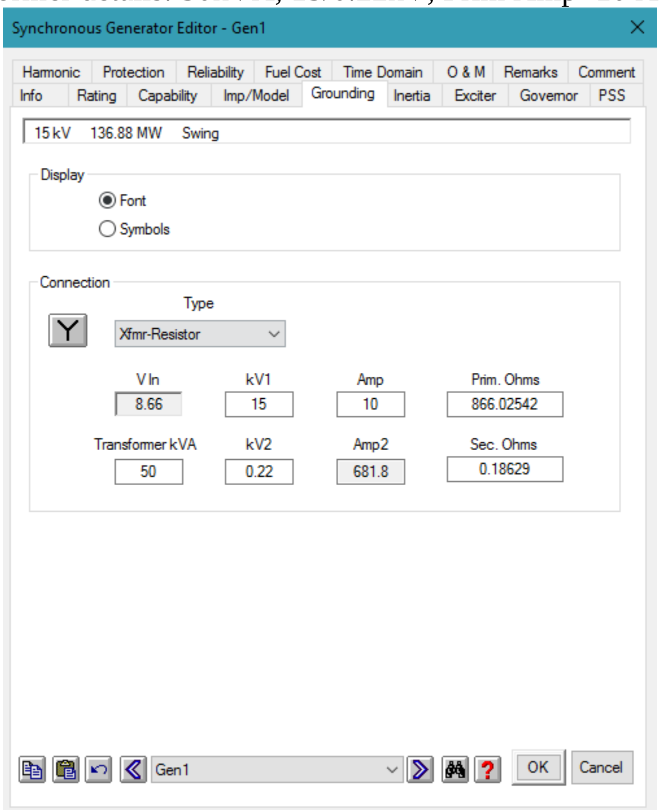
<u>Note:</u> Refer to sheet 3.14 for efficiency consideration and sheet 3.12 for capability curve points (Qa, Qb, Qc, Qd)

Generator Modelling

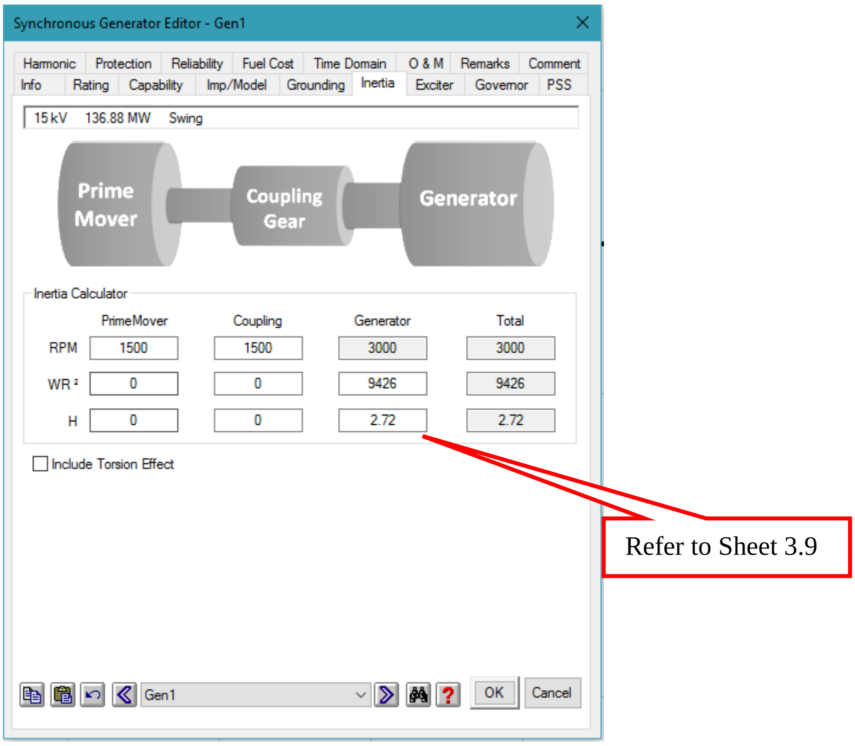


Note: Refer to sheet 3.13 for calculation of S_{break}, S_{100} and S_{120}.
Rdc is required in the case of SC study using GOST standard.

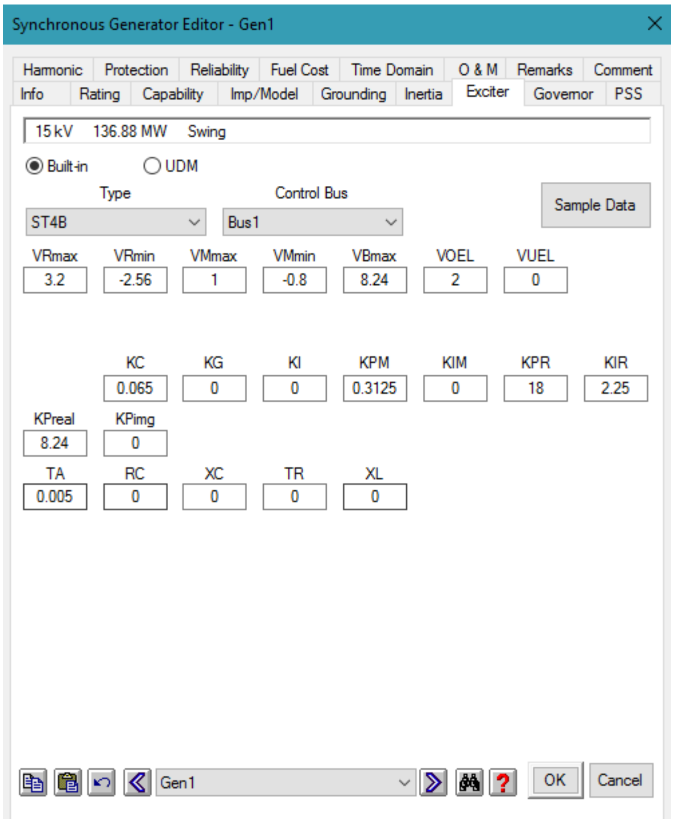
5. Make grounding as ‘Xfmr-Resistor’.
   Grounding transformer details: 50kVA, 15/0.22kV, Prim Amp=10 A



Generator Modelling

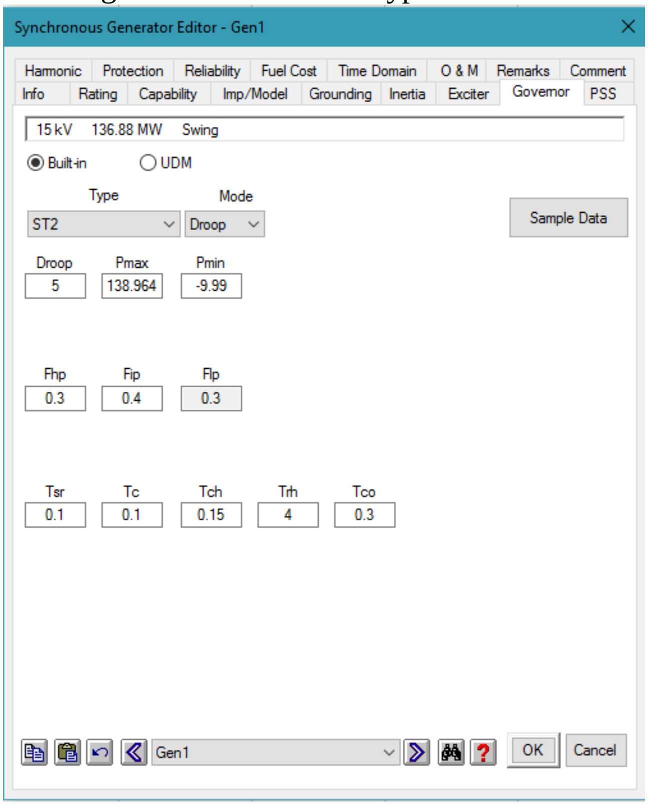


6. Select ST4B inbuilt exciter model and update all parameters as per 'Annex2- Summary Of Data'.



Generator Modelling

7. Choose ST-2 type inbuilt governor model with typical data.



<u>Note:</u> *Change Pmin from 0 to -9.99MW

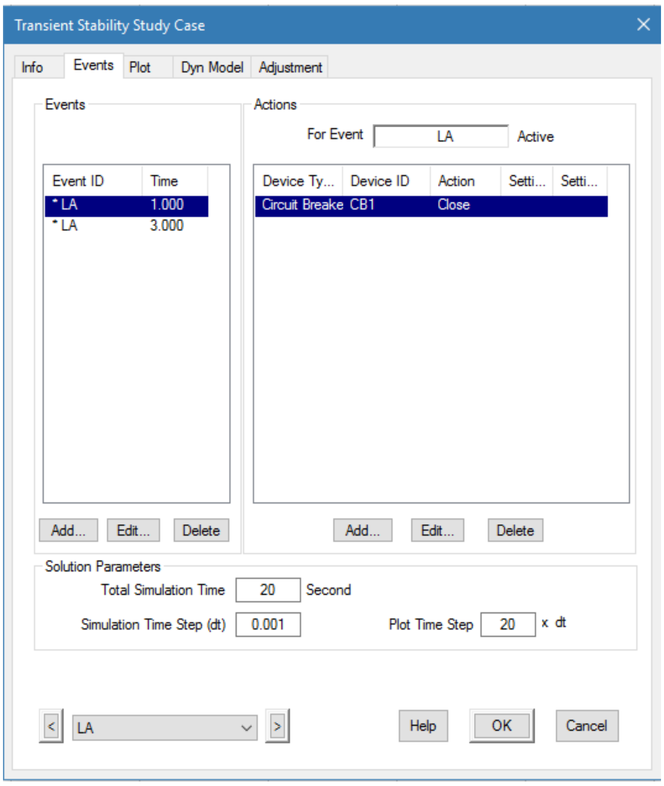
ANNEX-1

GENERATOR MODEL TESTING

Generator Modelling

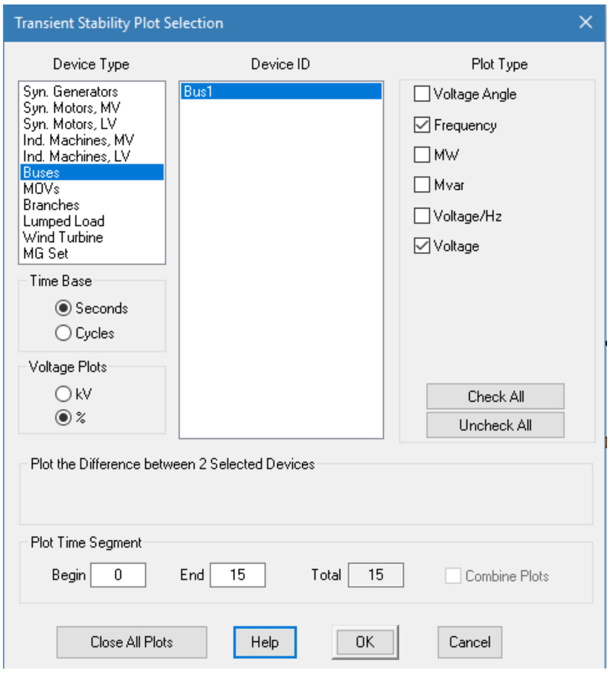
Case 1: Load Application on generator

1. To study load application on single generator, initially open CB1& CB2 connected to loads.
2. Go to the Transient Stability Study; and create a new study case as 'LA'.
3. Go to the events page and add two events to close CB1 at 1.0 sec and close CB2 at 3.0 sec as shown below.

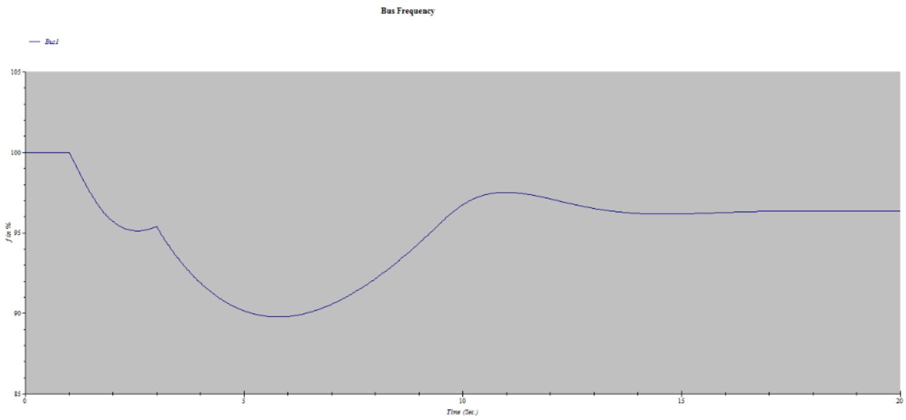


4. Go to plot page, Select Gen1 in Syn. Generator & Bus1 in Buses.
5. Run Transient stability, with output report name 'Load Application'.
6. Go to transient stability plots, and check results for bus voltage and bus frequency.

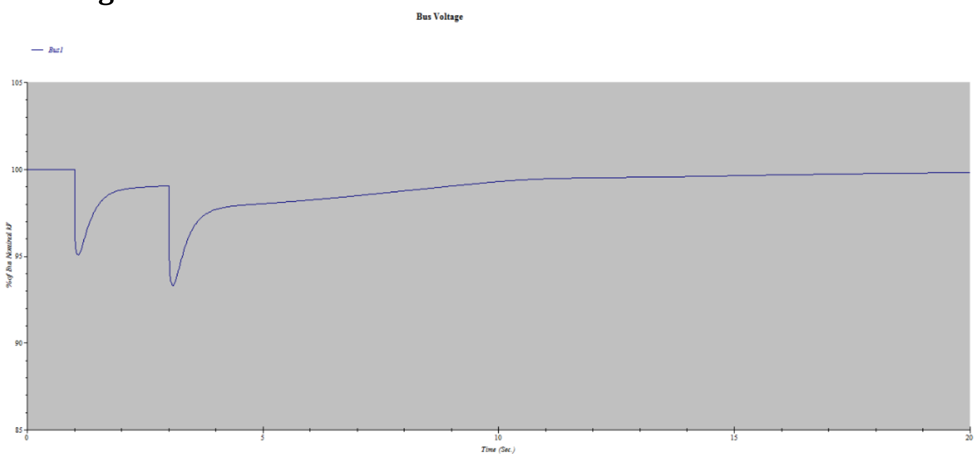
Generator Modelling



Bus Frequency



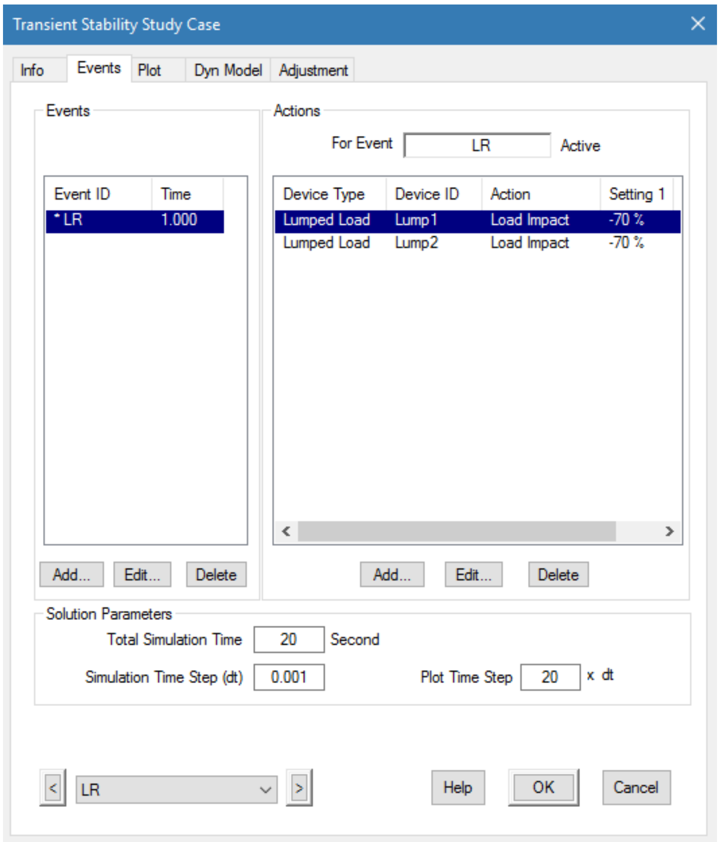
Bus Voltage

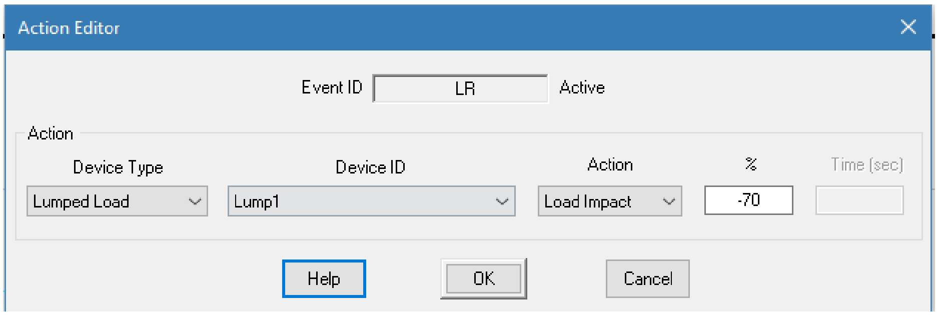


Generator Modelling

Case 2: 70% Load Rejection on generator

7.To study load Throw on single generator, initially close CB1& CB2 connected to loads.
8.Create a new study case as 'LR'.
9.Go to Events page and add an event to reduce both lumped load by 70% as shown below.

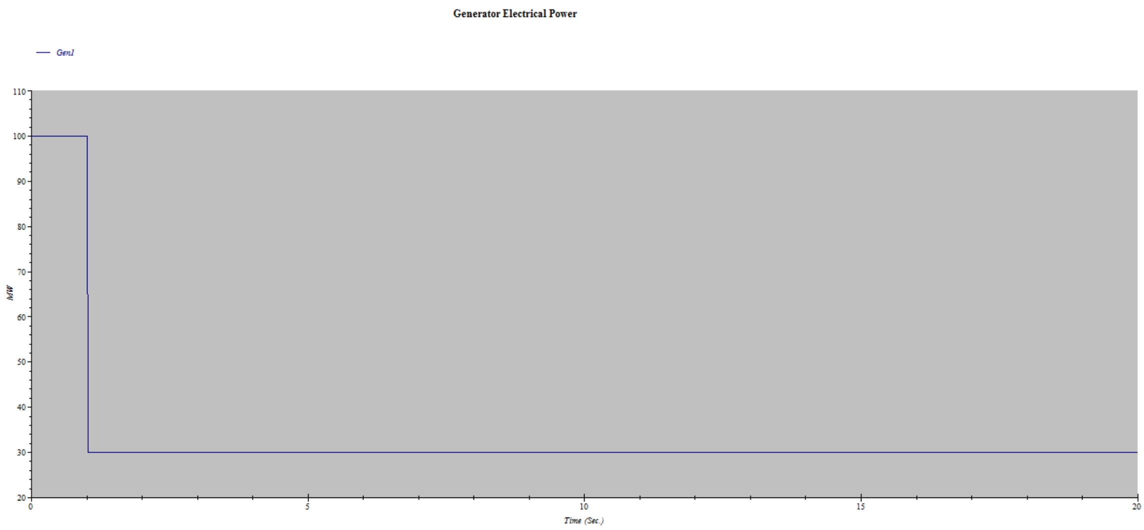




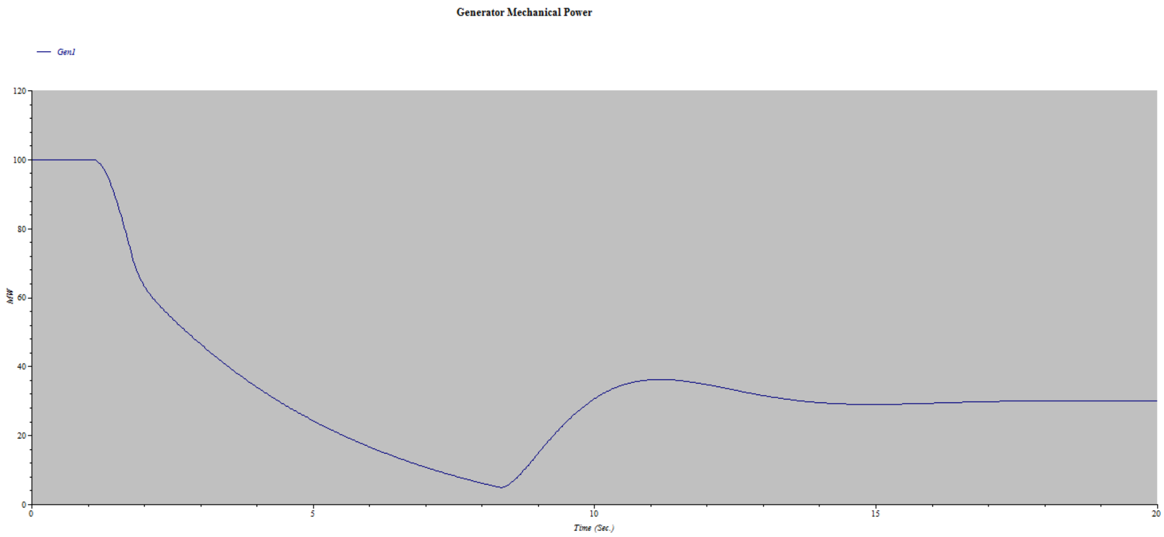
10. Go to plot page, Select Gen1 in Syn. Generator & Bus1 in Buses.
11. Run Transient stability, with output report name 'Load Rejection'.
12. Plot Generator electrical power and mechanical power, Generator Exciter Voltage (Efd), Bus voltage, Bus frequency as shown.

Generator Modelling

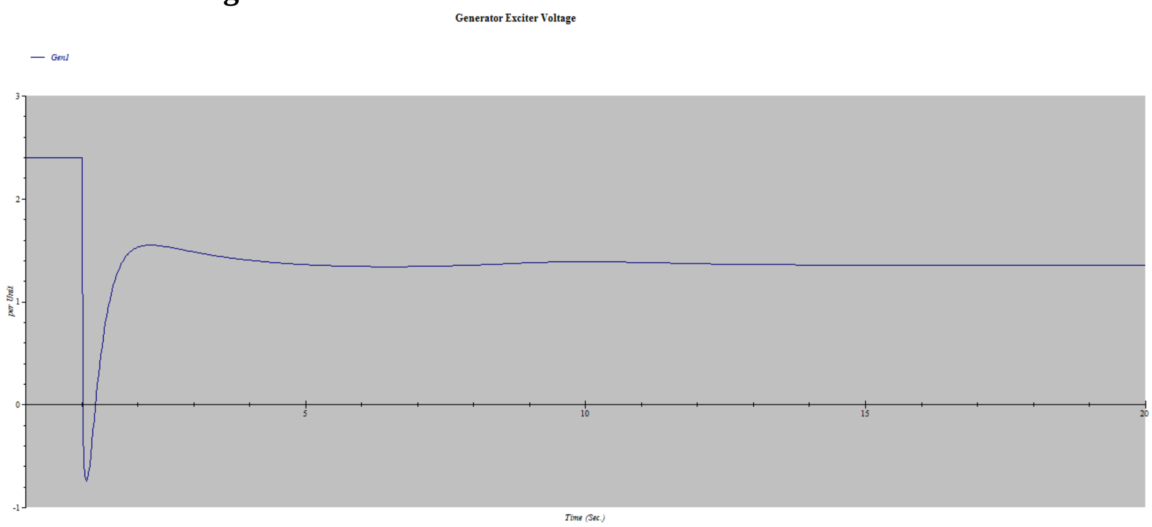
Gen Electrical power



Gen Mechanical power

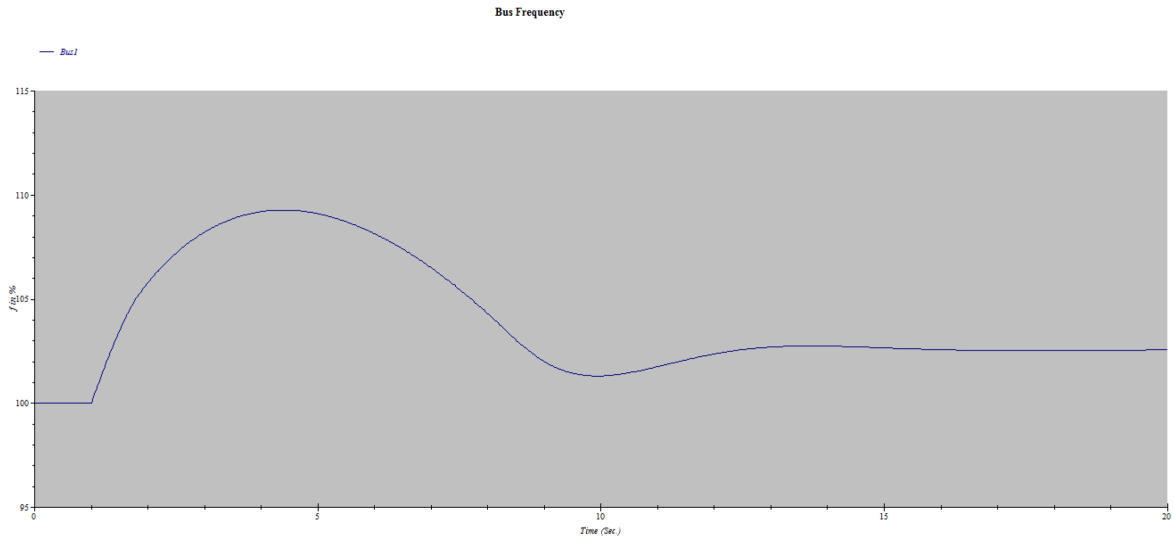


Gen Exciter Voltage

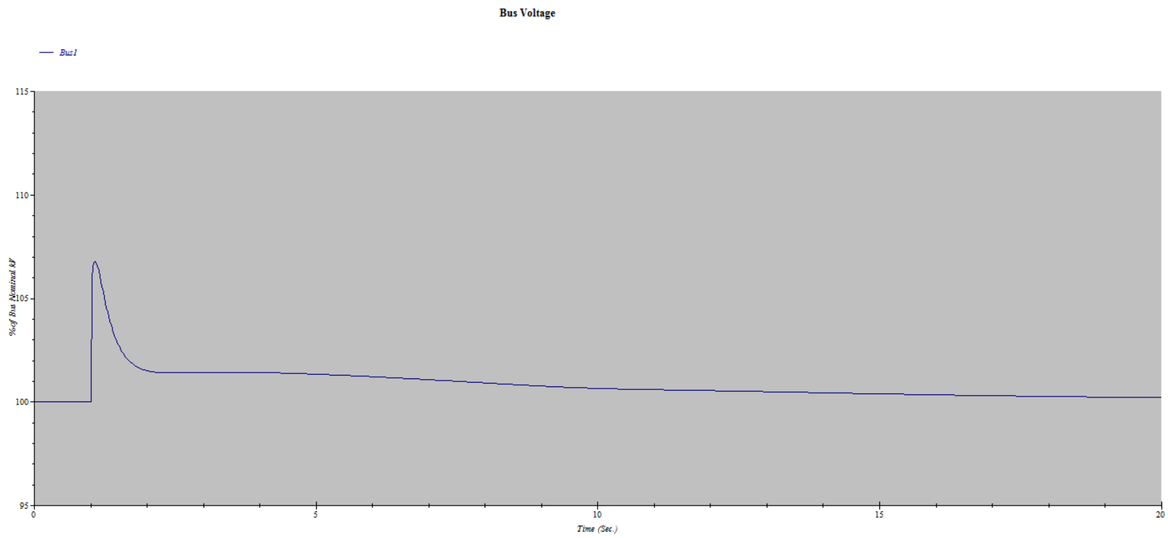


Generator Modelling

Bus Frequency



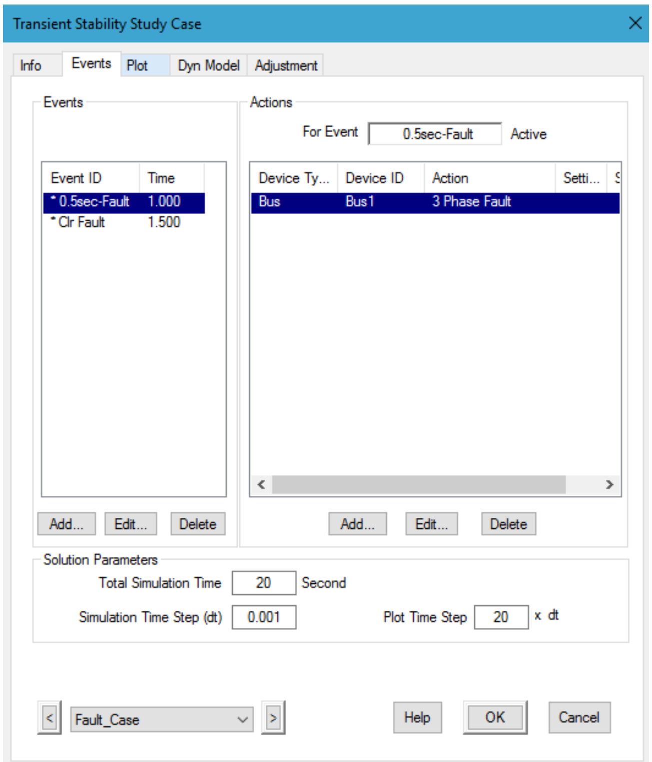
Bus Voltage



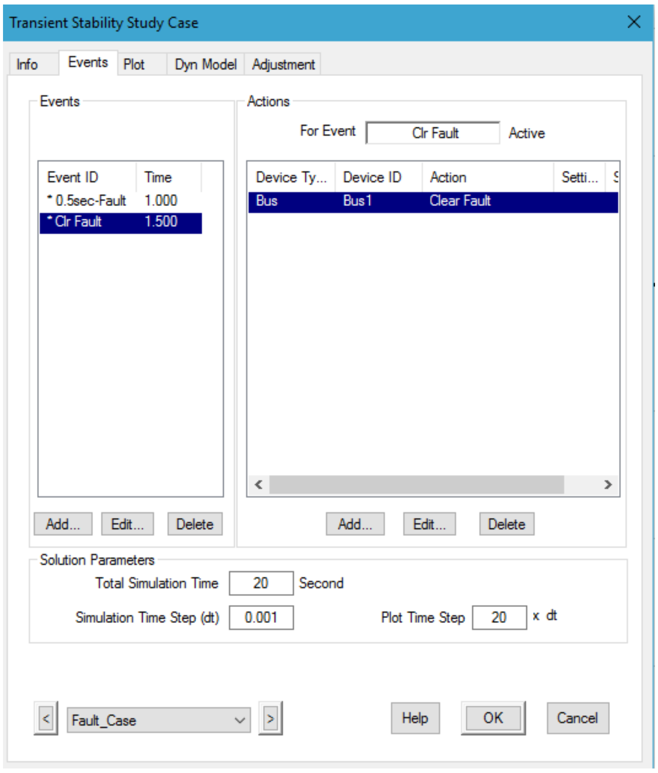
<u>Case 3: 0.5 sec fault on generator bus</u>

13. Create a New study case as ‘Fault_Case’.
14. Go to Events page and create an event for a 3-phase fault on Bus1 at 1 sec.

Generator Modelling



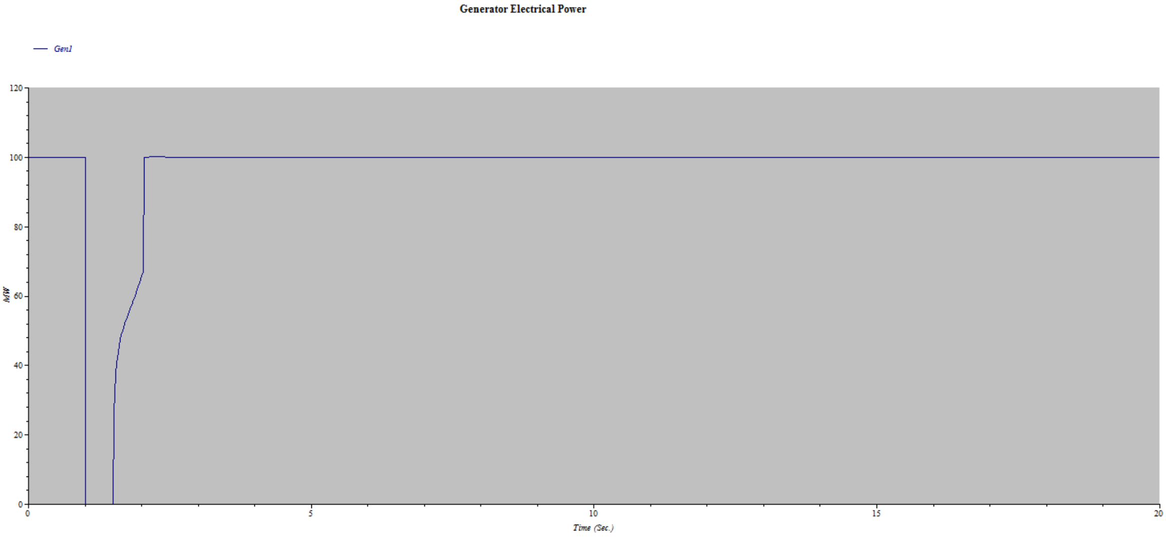
15. Create one more event to clear the fault on Bus1 at 1.5 sec.



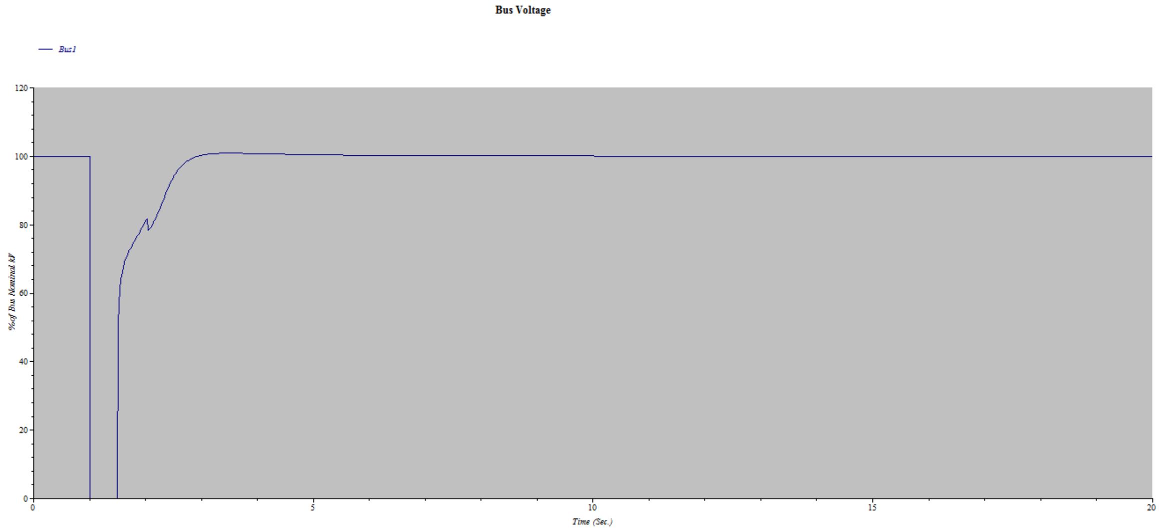
16. Go to plot page and plot Gen1 and Bus1.
17. Run transient stability with output report name as 'Fault_Case'.
18. Check the plots as shown below.

Generator Modelling

Gen Electrical power



Bus Voltage



ANNEX-2
SUMMAY OF DATA

Generator Modelling

Generator Inputs:

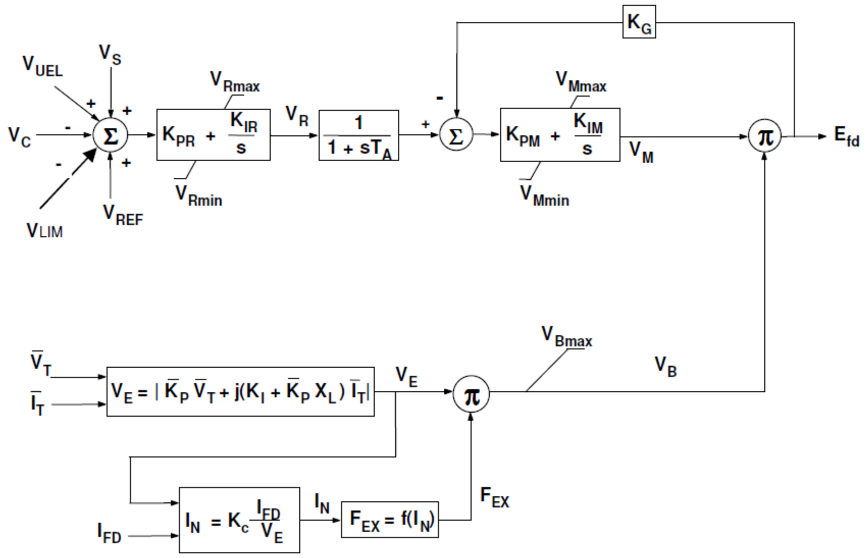
Parameter	Description	Rating	Unit
MVA	Generator MVA	171.11	MVA
MW	Engine MW Rating	136.88	MW
kV	Generator kV	15	kV
pf	Generator power factor	0.8	pu
Hz	Frequency	50	Hz
Pole	No. Of Poles	2	No.
Efficiency*	Generator Efficiency	**98.5***	%
Rotor type (Salient or round)	Round Rotor (Because of 2 poles)		
H	Total Engine & Generator Inertia Constant	2.72	MW-SEC/ MVA
D	Damping	5	% MW/Hz
Xd ”	d-axis sub-transient reactance	16.3±15%	%
Xd ’	d-axis transient reactance	23.3±15%	%
Xd,sat	d-axis synchronous reactance	213	%
Xq ”	q-axis sub-transient reactance	20	%
Xq ’	q-axis transient reactance	28	%
Xq,sat	q-axis synchronous reactance	200	%
X2	Negative sequence reactance	19.7	%
X0	Zero sequence reactance	9.8	%
XL	Leakage reactance	15	%
Xdu	Unsaturated d-axis synchronous reactance	228	%
Xqu	Unsaturated q-axis synchronous reactance	214	%
Ta	D.C Armature time Constant	0.6	Sec.
X/ R (calc)	X/R ratio	188.5	ratio
T do ”	d-axis open ckt. sub-transient time constant	0.05	Sec.
T do ’	d-axis open ckt. transient time constant	15	Sec.
T qo ”	q-axis open ckt. sub-transient time constant	0.05	Sec.
T qo '	q-axis open ckt. transient time constant	4.7	Sec.
Sbreak*	p.u of terminal voltage at which saturation curve screws the air gap line	**0.88***	pu
S100*	Saturation factor at 100 % voltage	**1.077***	If100/If
S120*	Saturation factor at 120 % voltage	**1.388***	If120/ 1.2If

Note:

- Ta = L/R= 0.6 sec
  X/R= 2*pi*f*(L/R) = 2*pi*50*0.6 =188.5
- Xdu & Xqu are not mentioned in vendor datasheet. However, they can be calculate by using formulae’s: Xd,sat = Ksd * (Xd,unsat - XL) + XL
  Xq,sat = Ksq * (Xq,unsat - XL) + XL
  Where, Ksd=Ksq= (1/S_{100})
- * Calculation of these value is shown in Sheet No 3.13 & 3.14.
  Remaining values are as per ‘Annex-3: Actual Vendor Datasheet’.

Generator Modelling

Exciter Inputs: **IEEE ST4B** exciter model



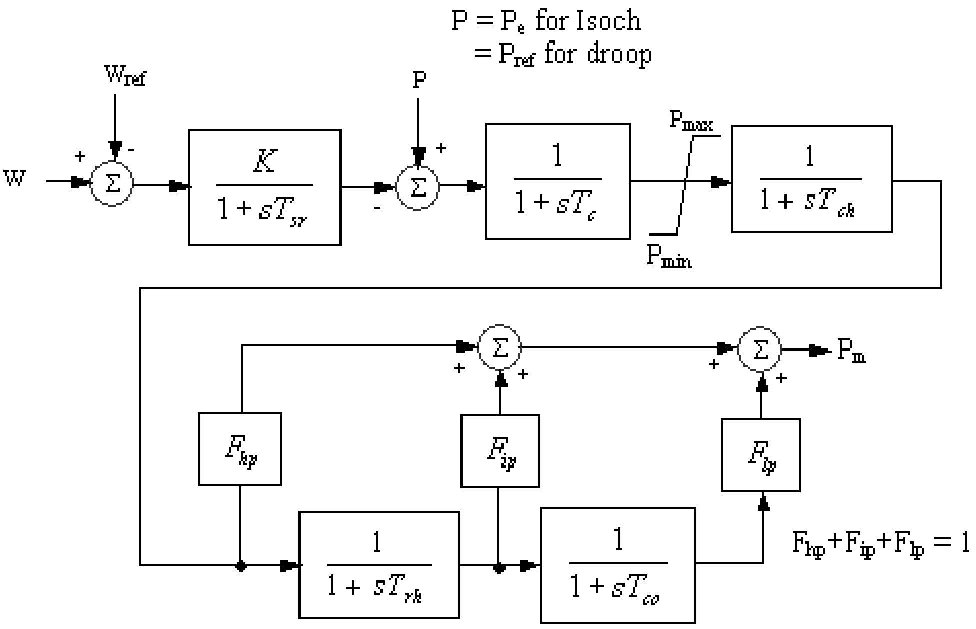
Type ST4B - Potential or Compound-Source Controlled Rectifier Exciter

Parameter	Description	Value	Unit
VRmax	Maximum AVR output	3.2	p.u.
VRmin	Minimum AVR output	-2.56	p.u.
VMmax	Maximum inner loop output	1	p.u.
VMmin	Minimum inner loop output	-0.8	p.u.
VBmax	Maximum Source Voltage	8.24	p.u.
VOEL*	Over excitation limit input	**2***	p.u.
VUEL*	Under excitation limit input	**0***	p.u.
KC	Rectifier loading factor	0.065	p.u.
KG	Field voltage feedback gain	0	p.u.
KI	Current source constant (on system base – 100MVA)	0	p.u.
KPM	Inner loop proportional gain	0.3125	p.u.
KIM	Inner loop integral gain	0	p.u.
KPR	AVR proportional gain	18	p.u.
KIR	AVR integral gain	2.25	p.u.
KPreal	Real part of potential source constant	8.24	p.u.
KPimg*	Imaginary part of potential source constant	**0***	p.u.
TA	AVR time constant	0.005	sec.
TR*	AC sensor time constant	**0***	sec.
XL	Source leakage reactance	0	p.u.
Rc*	Resistive component of load compensation	**0***	p.u.
Xc*	Reactive component of load compensation	**0***	p.u.

Note: * values are the typical etap default values for exciter model.
Remaining values are as per Sheet 3.10 & 3.11 i.e. Exciter Datasheet.

Generator Modelling

Governor Inputs: **ST-2** inbuilt governor model



Compound Single-Reheat Steam-Turbine (ST2)

Parameter	Description	Value	Unit
Mode	Droop or Isoch	Droop	
Droop	Steady-state speed droop	5	%
Pmax	Maximum shaft power	138.09	MW
Pmin	Minimum shaft power	**-9.99***	MW
Fhp	(Shaft capacity ahead of reheater)/(Total shaft capacity)	0.3	p.u.
Fip	Intermediate pressure turbine power fraction	0.4	p.u.
Flp	Low pressure turbine power fraction	0.3	p.u
Tsr	Speed relay time constant	0.1	sec.
Tc	Control Amplifier (servomotor) time constant	0.1	sec.
Tch	Steam chest time constant	0.15	sec.
Trh	Reheater time constant	4	sec.
Tco	Crossover time constant	0.3	sec.

Note: All Values are etap default one.
*Change Pmin from 0 to -9.99MW.

ANNEX-3

ACTUAL VENDOR DATASHEET

VENDOR

ELECTRICAL DATA SHEET

1. RATING DETAILS

1.1	Frame size	
1.2	Terminal voltage	15.00 kV
1.3	Frequency	50 Hz
1.4	Speed	3000 rev/min
1.5	Power factor	0.800
1.6	Applicable national standard	IEC 60034-3
1.7	Rated coolant inlet temperature	35.0 °C
1.8	Rated output	136.888MW, 171.110 MVA
1.9	Rated current	6586 amps
2.0	Ambient air temperature	< or = 50 °C
2.1	Installation	Indoor

2. PERFORMANCE CURVES

2.1	Output vs coolant inlet temperature	Ref. No. 1
2.2	Generator capability diagram	Ref. No. 2
2.3	Efficiency vs output	Ref. No. 3
2.4	Open and short circuit curves	Ref. No. 4
2.5	V-curves	Ref. No. 5
2.6	Permitted duration of negative sequence current	Ref. No. 6

3. REACTANCES

3.1	Direct axis synchronous reactance, Xd(i)	213 %
3.2	Direct axis saturated transient reactance, X'd(v)	23.3 % ± 15 %
3.3	Direct axis saturated sub transient reactance, X"d(v)	16.3 % ± 15 %
3.4	Unsaturated negative sequence reactance, X2(i)	19.7 %
3.5	Unsaturated zero sequence reactance, X0(i)	9.8 %
3.6	Quadrature axis synchronous reactance Xq(i)	200 %
3.7	Quadrature axis saturated transient reactance X'q(v)	28 %
3.8	Quadrature axis saturated sub transient reactance X"q(v)	20 %
3.9	Damping	5% MW/Hz
3.10	Short circuit ratio	0.50
3.11	Leakage Reactance	15%

VENDOR

ELECTRICAL DATA SHEET - CONTINUATION

136.888 MW, 0.800 pf, 15.00 kV, 50 Hz

4. RESISTANCES AT 20°C

4.1	Rotor resistance	0.092 ohms
4.2	Stator resistance per phase	0.0011 ohms

5. TIME CONSTANTS AT 20°C

5.1	D-axis O.C. transient time constant, T'_{do}	15.0 seconds
5.2	Q-axis O.C. transient time constant, T'_{qo}	4.7 seconds
5.3	D-axis O.C. sub transient time constant T''_{do}	0.05 seconds
5.4	Q-axis O.C. sub transient time constant, T''_{qo}	0.05 seconds
5.5	D.C. Armature Time Constant, Ta	0.6 seconds

6. INERTIA

6.1	Moment of inertia, WR^2 (See note 2)	3915 $Kg.m^2$
6.2	Inertia constant, H	1.13 kW.secs/kVA

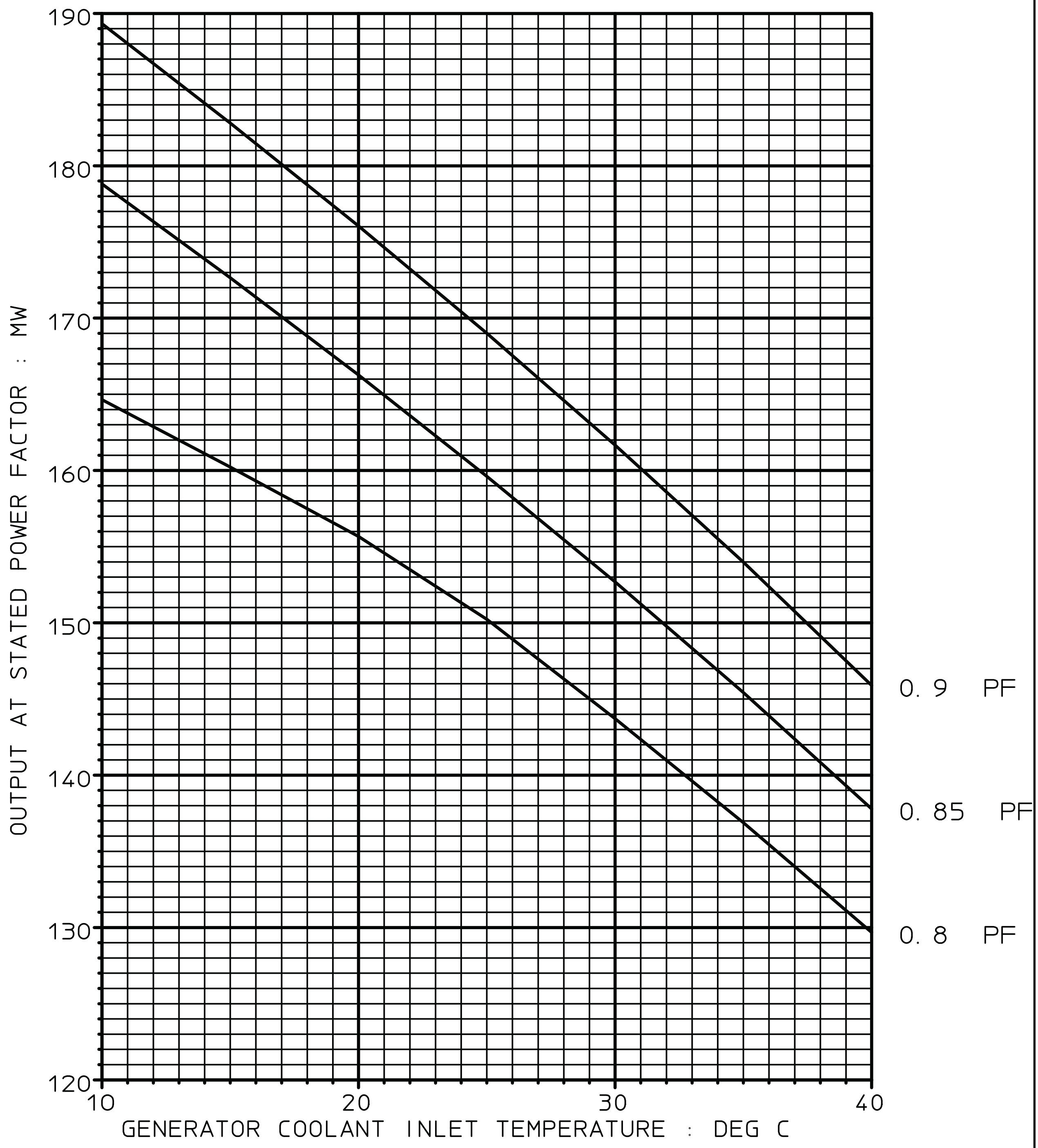
7. CAPACITANCE

7.1	Capacitance per phase of stator winding to earth	0.56 microfarad

8. EXCITATION

8.1	Excitation current at no load, rated voltage	562 amps
8.2	Excitation voltage at no load, rated voltage	52 volts
8.3	Excitation current at rated load and P.F.	1634 amps
8.4	Excitation voltage at rated load and P.F.	203 volts
8.5	Inherent voltage regulation, F.L. to N.L.	36 %

VARIATION OF GENERATOR OUTPUT WITH COOLANT TEMP



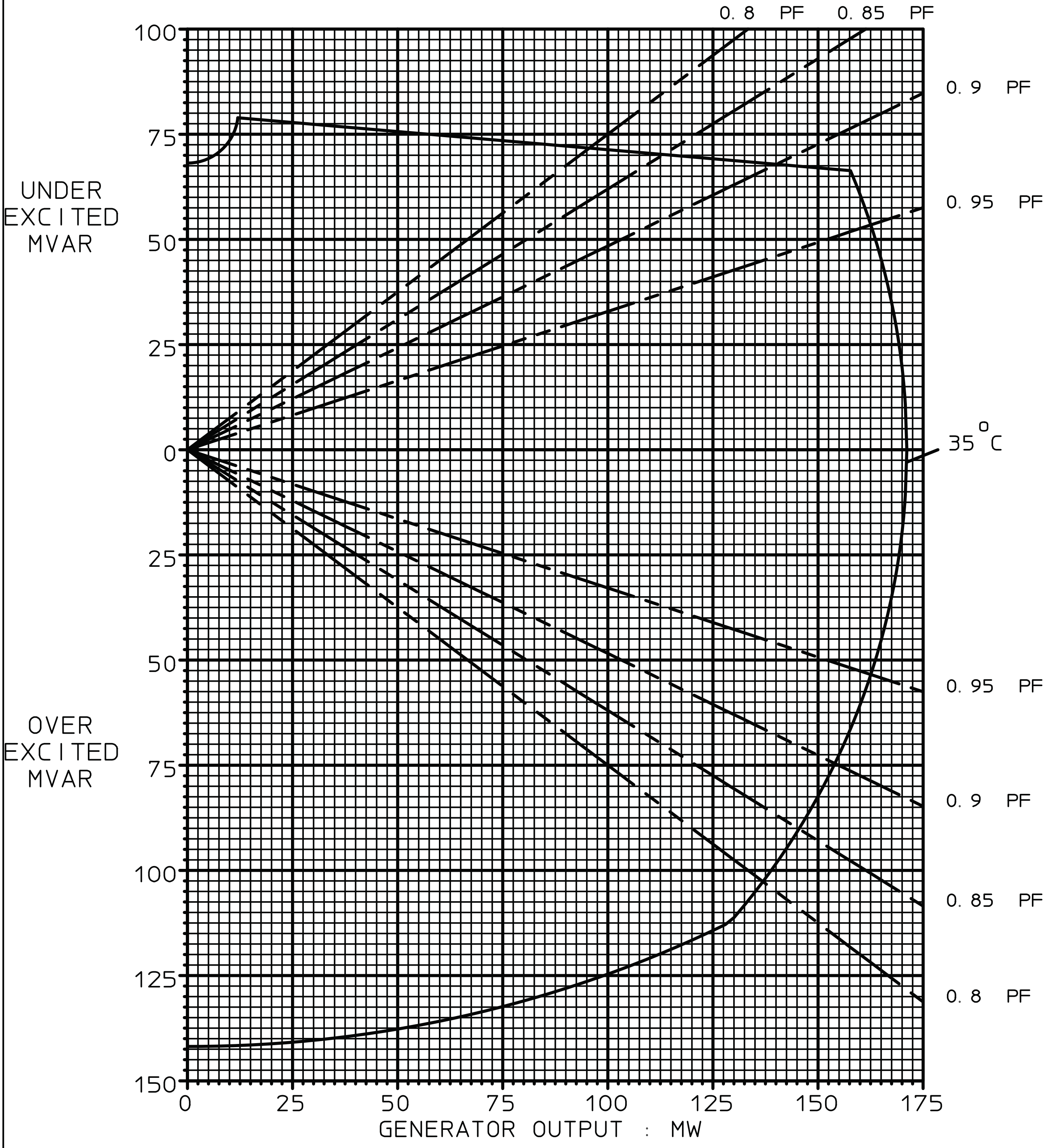
15. 00KV, 3 Ph, 50Hz.

Up to 1000 meters ASL

Coolant: Fresh Water

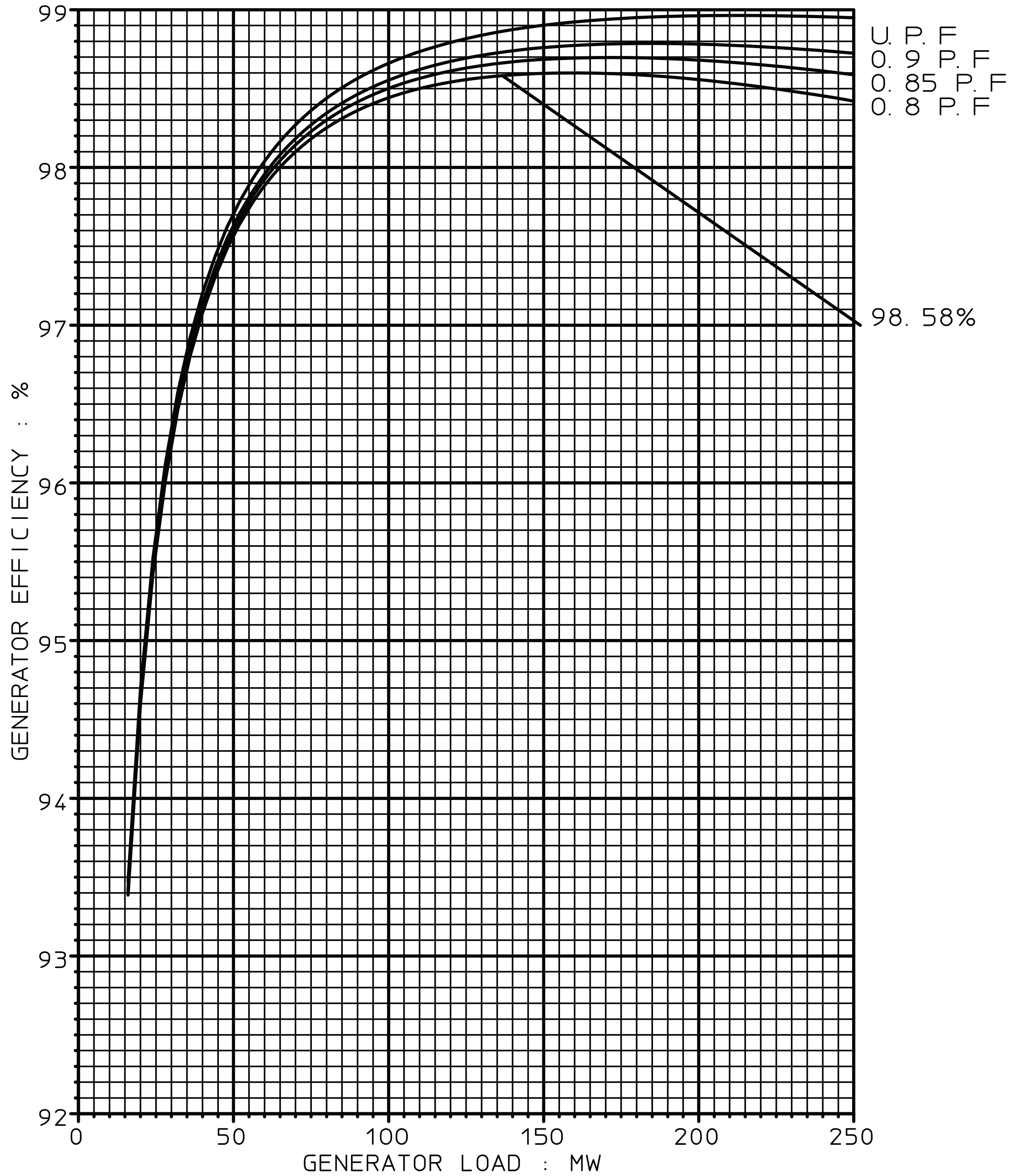
IN ACCORDANCE WITH
IEC 60034-3
Class B temperatures.
Total temperatures Stator 122 Deg C
Rotor 130 Deg C

GENERATOR CAPABILITY DIAGRAM



	IN ACCORDANCE WITH
15. 00KV, 3 Ph, 50Hz.	IEC 60034-3
	Class B temperatures.
Up to 1000 meters ASL	Total temperatures Stator 122 Deg C
	Rotor 130 Deg C
Coolant:	Fresh Water

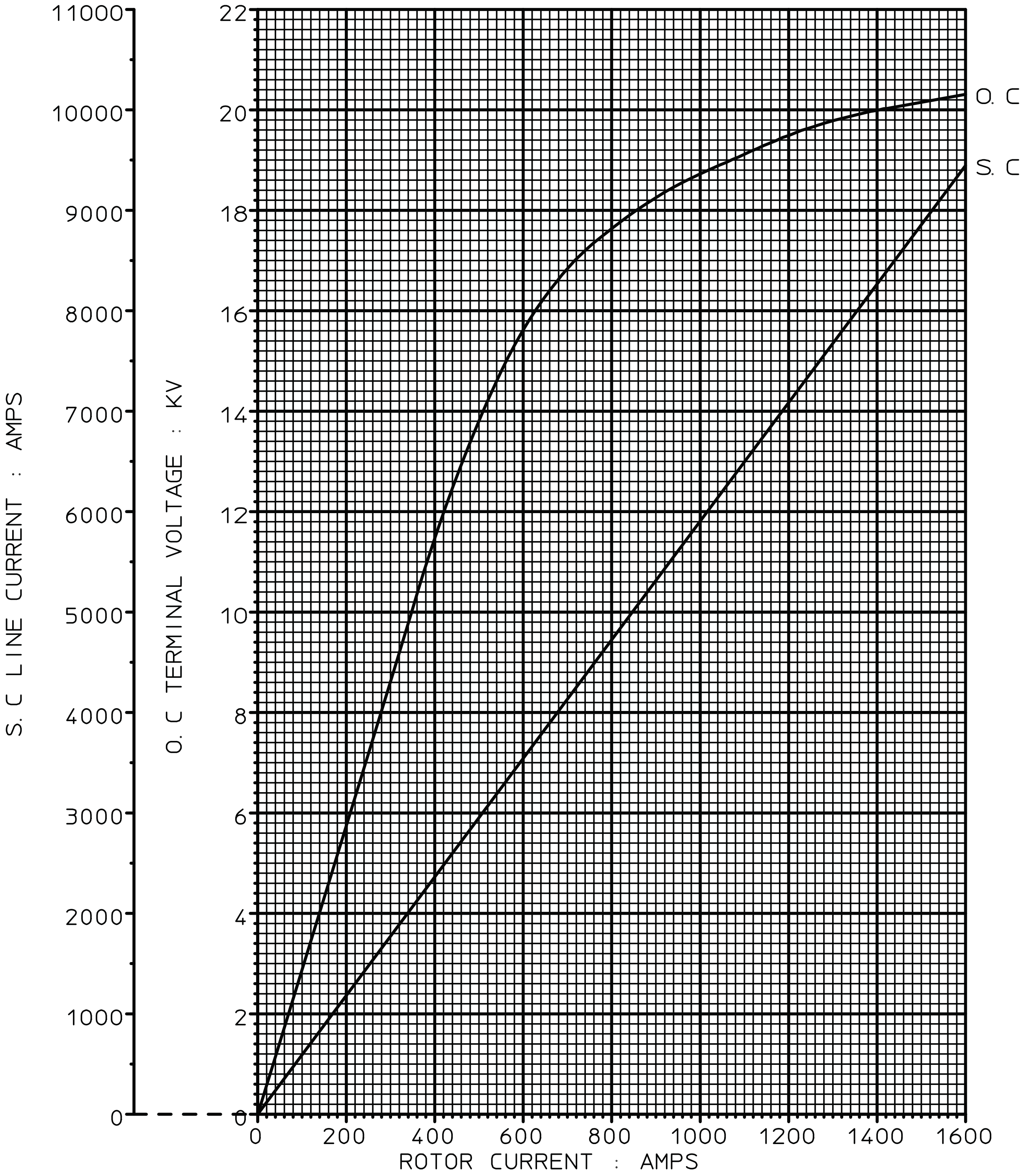
VARIATION OF GENERATOR EFFICIENCY WITH LOAD



15 KV, 3 Ph, 50 Hz.

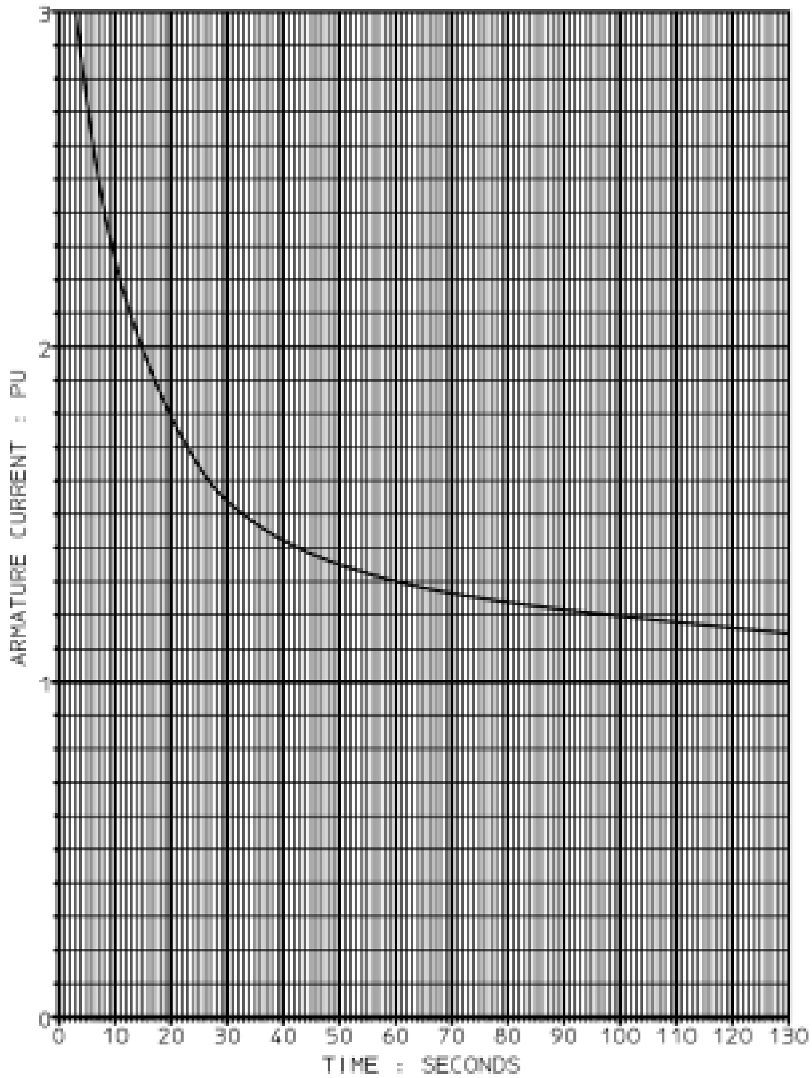
Efficiencies shown are guaranteed subject to the tolerance specified in IEC 60034-1.

OPEN CIRCUIT AND SHORT CIRCUIT CHARACTERISTIC



3Ph, 50Hz, 3000 RPM.

PERMITTED DURATION OF GENERATOR ARMATURE CURRENT

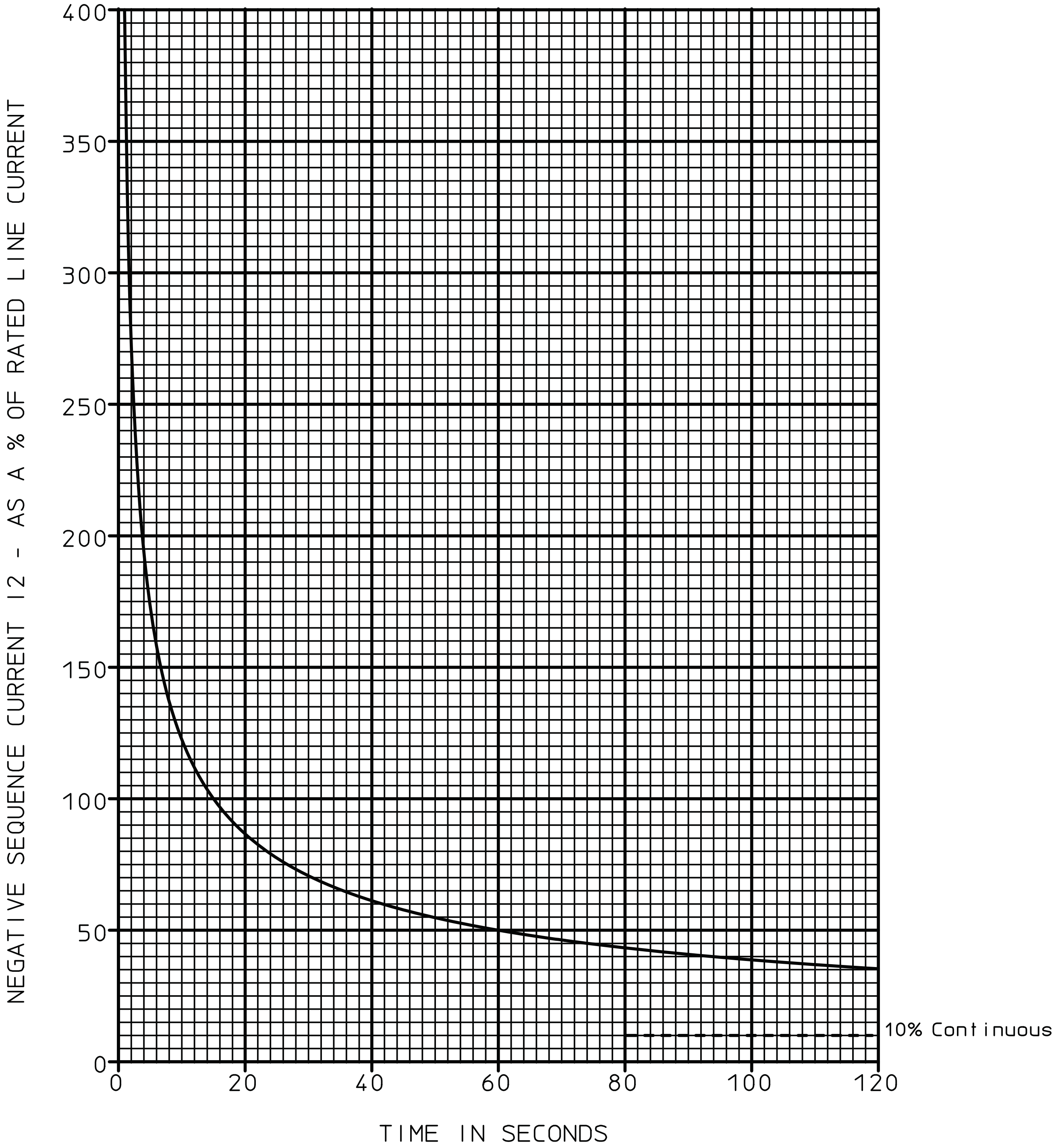


All DAX Generators

For continuous operation, rated current should not be exceeded in any one phase.

PERMISSIBLE DURATION OF NEGATIVE SEQUENCE CURRENT

$$I_2^2 t = 15$$



NOTE: For continuous operation rated current must not be exceeded in any one phase.

INERTIA DATA FOR GENERATOR & TURBINE			
PARAMETERS	**UNITS**	**DESCRIPTION**	**VALUES**
MW	MW	Steam Turbine MW Rating	136.88
GEN_RPM	RPM	Generator RPM	**3000**
TURB_RPM	RPM	TURBINE RPM	**7116**
Stored KE GEN	MJ or MW-s	Generator Stored Kinetic Energy (IP-GEN)	458,2
Stored KE TURB	MJ or MW-s	Steam Turbine Stored Kinetic Energy (HP)	6,7
ωr^2 Gen	kg-m2	Inertia J of Generator At Generator RPM	3842
ωr^2 TURB	kg-m2	Inertia J of Turbine At Turbine RPM	**11**
		Inertia J of Turbine At Generator RPM As Base	**5430**
Where $J = \omega r^2$ and r is radius of gyration			

Calculation of Inertia Constant H:
H= (K.E. stored in Gen & Turb)/ MVA rating of Generator
=(458.2+6.7)/171.11
=2.72 MW-Sec/MVA

VENDOR	IEEE ST4B Model Setting	TI No.:	
		Rev	
Technical Information		Date	

1. Introduction

This technical information gives brief instructions for calculation of IEEE ST4B model parameters.
It shows the general approach and formulas.

2. Additional parameters needed for the standard ST4B model parameters computation

AVR setting (real AVR constants):

C061 [-] AVR proportional gain – typical value 18
C062 [ms] AVR Integral Time Constant – typical value 8000
C038 = RFT [0.01 Ohm] Field winding resistance (hot) – *not mandatory*

Excitation transformer:

Snt [VA] Excitation transformer apparent nominal power
Ek [%] Excitation transformer short circuit voltage
Utsec [V AC] Secondary voltage of excitation transformer
Xnt [Ohm] Xnt=Utsec*Utsec / Snt Excitation transformer nominal reactance

Excitation values:

Ufn [V DC] Generator nominal field voltage
Ifn [A DC] Generator nominal field current
Rf [Ohm] Generator field winding resistance (hot) - choose the biggest value from following options: Rf = 100*C038 or Rf = Ufn / Ifn or the "hottest" value
Uff [V DC] Excitation ceiling voltage (short time, according to contract/project)

Generator:

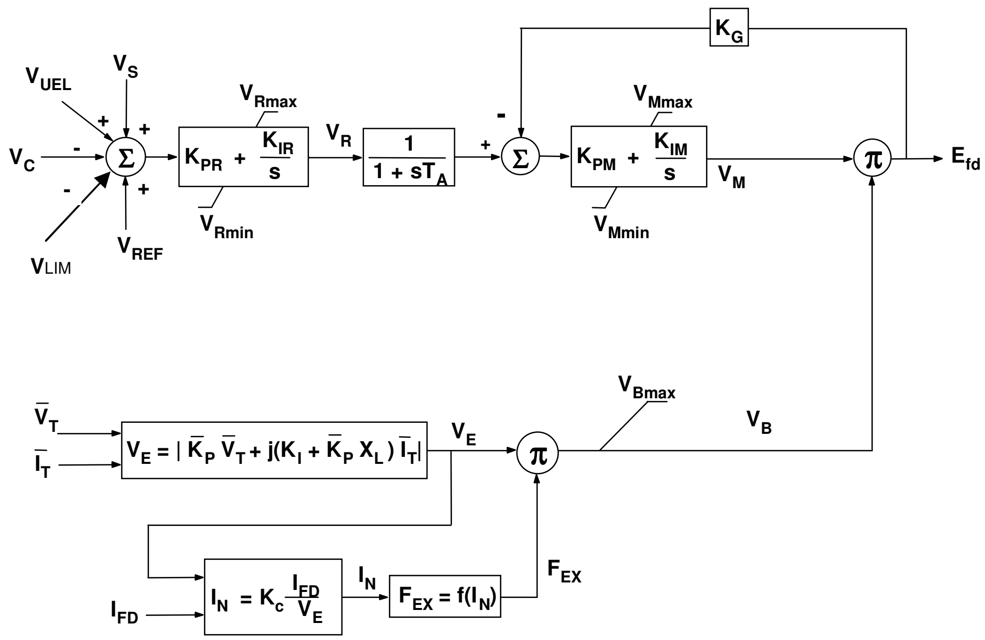
Ifn0 [A DC] Get the generator no-load saturation characteristic, construct a tangent line from the beginning of the saturation characteristic (= air-gap line) and read the value of field current corresponding to the generator nominal voltage on the air-gap line – name this value Ifn0 it is 1 p.u. of generator field current.
Ufn0 [V DC] Ufn0 = Ifn0 * Rf It is 1 p.u. of generator field voltage.

Assumed parameters:

C061=18 [-] – typical value
C062=8000 [ms] – typical value
C038= N/A – *not mandatory*
Snt=1250000 [VA]
Ek=6 [%]
Utsec=420 [V AC]
Xnt=0,141 [Ohm] Xnt=Utsec*Utsec / Snt
Ufn=201 [V DC] from generator datasheet
Ifn=1620,2 [A DC] from generator datasheet
Rf=0,124 [Ohm] Rf = Ufn / Ifn
Uff=504 [V DC]
Ifn0=493 [A DC] 1 p.u. of generator field current. No-load characteristic was unavailable, value estimated (0,9 * no load field current)
Ufn0=61,16 [V DC] Ufn0 = Ifn0 * Rf It is 1 p.u. of generator field voltage.

Approved by:		Authorised by:	

VENDOR	IEEE ST4B Model Setting	TI No.	
		Rev	
Technical Information		Date	



Type ST4B - Potential or Compound-Source Controlled Rectifier Exciter

3. IEEE ST4B model parameters

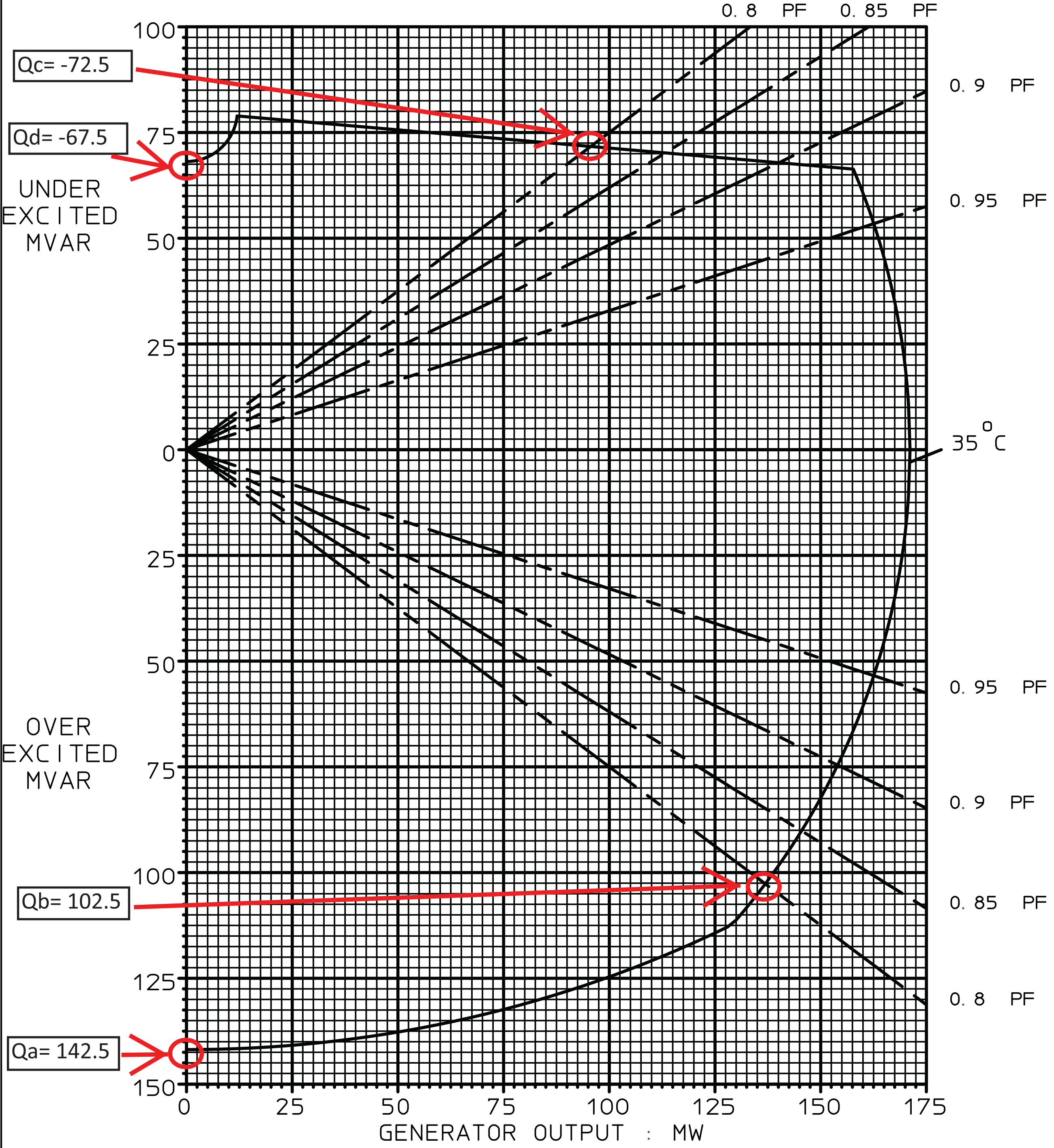
K_{PR} = C061 Voltage regulator proportional gain 18 [-]
K_{IR} = 1000*C061/C062 Voltage regulator integral gain (Active only with closed gen. breaker!). 2,25 [Sec]
Note: K_{IR}=0 When the generator breaker is open only proportional regulation is used at no load run of the generator!

K_{PM} = 1/3.2 = 0.3125 Voltage regulator proportional gain (normalises the output to +/- 1) 0,3125*
K_{IM} = 0 Voltage regulator integral gain (not in A50 structure) 0*
K_G =0 Feedback gain constant of the inner loop field regulator (not in A50 structure) 0*
T_A =0.005 Voltage regulator time constant (delay of thyristor control) 0,005 Sec*
V_{Rmax}=3.2 Maximum voltage regulator output (corresponds to integer range) 3,2 p.u*
V_{Rmin}=0.8*-3.2 =-2.56 Minimum voltage regulator output (corresponds to integer range) (corresponds to integer range and fire-through prevention) -2,56 p.u*
V_{Mmax}=1 Maximum voltage regulator output (fixed value) 1 p.u*
V_{Mmin}=-0,8 Minimum voltage regulator output (corresponds to fire-through prevention) -0,8 p.u*
V_{Bmax}= Uff / Ufn0 Available exciter voltage (ceiling voltage in p.u.) 8,24 p.u

K_I=0 Potential circuit gain coefficient (not in A50 structure or omitted) 0*
X_L=0 Reactance associated with potential source (not in A50 structure or omitted) 0*
K_P= V_{Bmax} Potential circuit gain coefficient (set identically as V_{Bmax}) 8,24 p.u.
K_C = (3/π) * (Ek / 100) * (Xnt / Rf) Rectifier loading factor proportional to commutating reactance (found in the literature) 0,065 [-]
* - Values with this (*) sign are fixed – project independent

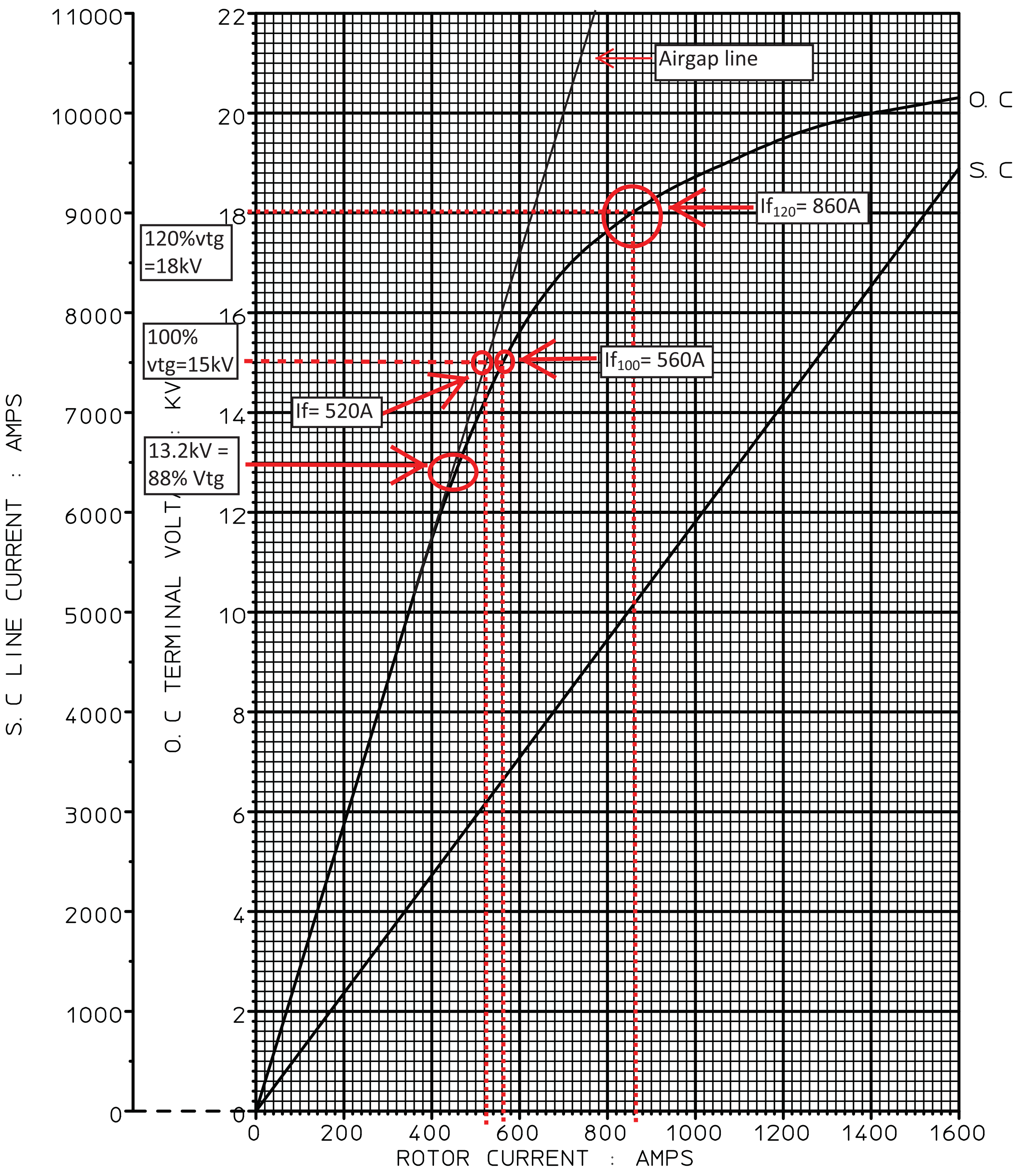
Note: Parameters K_{PM}, K_{IM}, K_G, T_A, V_{Rmax}, V_{Rmin}, V_{Mmax}, V_{Mmin}, K_I, X_L are supposed to be always the same (fixed). They are not variable and they are independent of the particular project / contract. Their values correspond to the current design of A50 firmware and hardware or they are set such a way to fit the model structure given that the model does not fully correspond to the physical A50 structure. Limits or factors equal to number +/- 3.2 correspond to limitation of the numerical 16 bit integer range if assumed that number 10 000 represents 1 p.u. inside the regulator (+/- 32768 / 10 000 = +/- 3.2768 but the particular functions inside the regulator use only range +/- 32000 i.e. +/- 3.2 p.u.).

GENERATOR CAPABILITY DIAGRAM



	IN ACCORDANCE WITH
15. 00KV, 3 Ph, 50Hz.	IEC 60034-3
	Class B temperatures.
Up to 1000 meters ASL	Total temperatures Stator 122 Deg C
	Rotor 130 Deg C
Coolant :	Fresh Water

OPEN CIRCUIT AND SHORT CIRCUIT CHARACTERISTIC



3Ph, 50Hz, 3000 RPM.

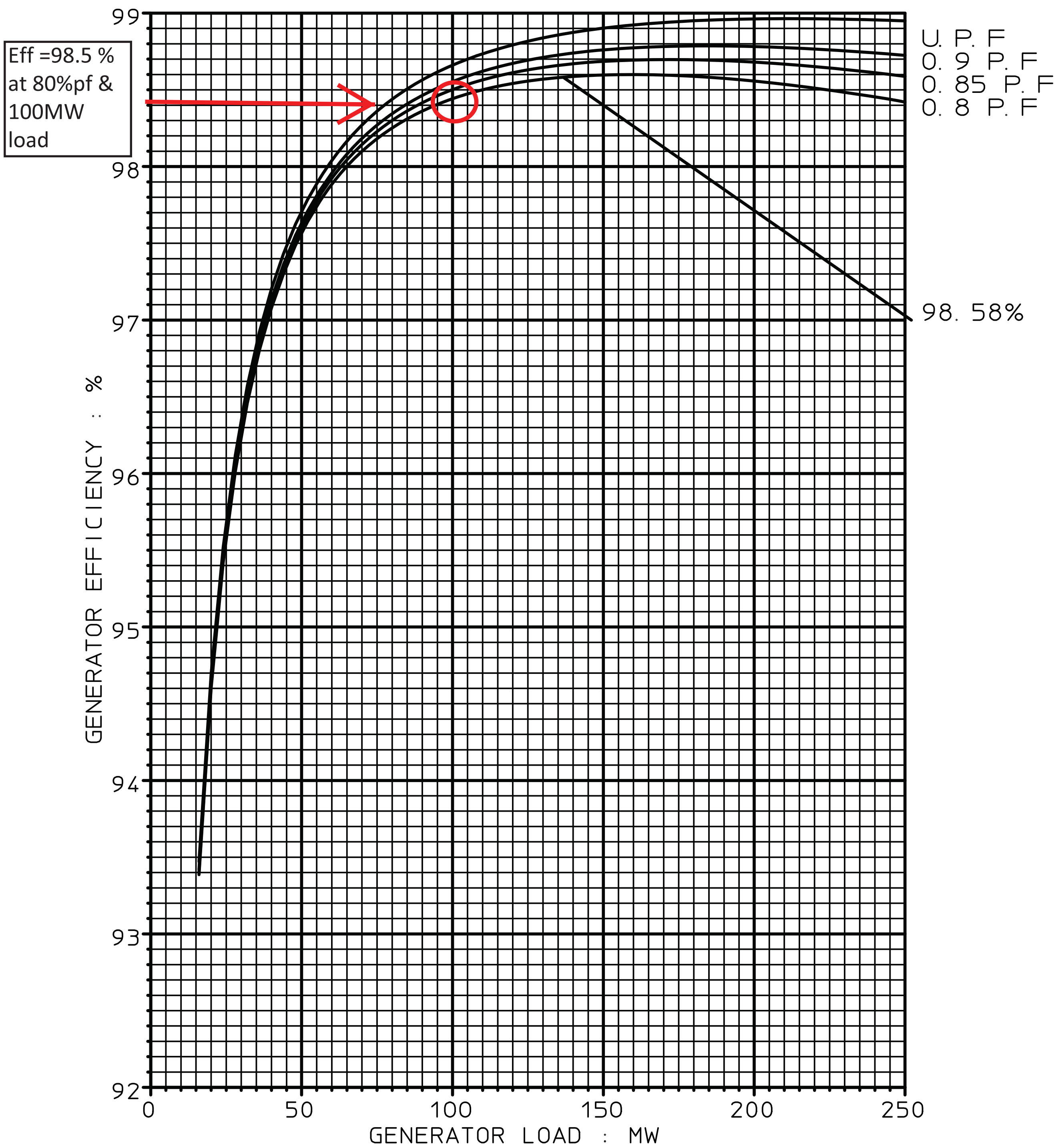
Calculation:

S_{100}=(If_{100}/ If) = 560/520 = 1.077

S_{120}=(If_{120}/1.2* If)= 860/1.2*520 = 1.388

Sbreak= 0.88

VARIATION OF GENERATOR EFFICIENCY WITH LOAD



15 KV, 3 Ph, 50 Hz.

Efficiencies shown are guaranteed subject to the tolerance specified in IEC 60034-1.