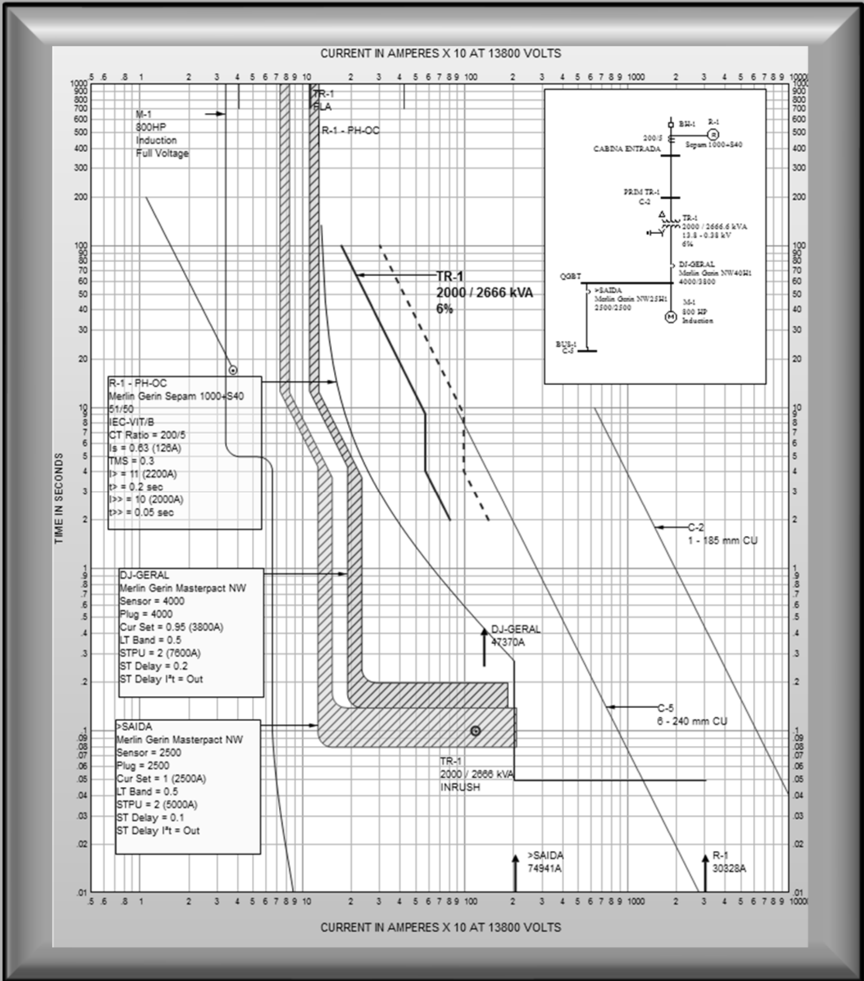

EngePower® TREINAMENTOS

TIPS AND ENGINEERING PRACTICES ON PROTECTION AND OVERCURRENT COORDINATION

EasyPower® Power made easy

Part 2/2

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1st Edition
2nd Revision

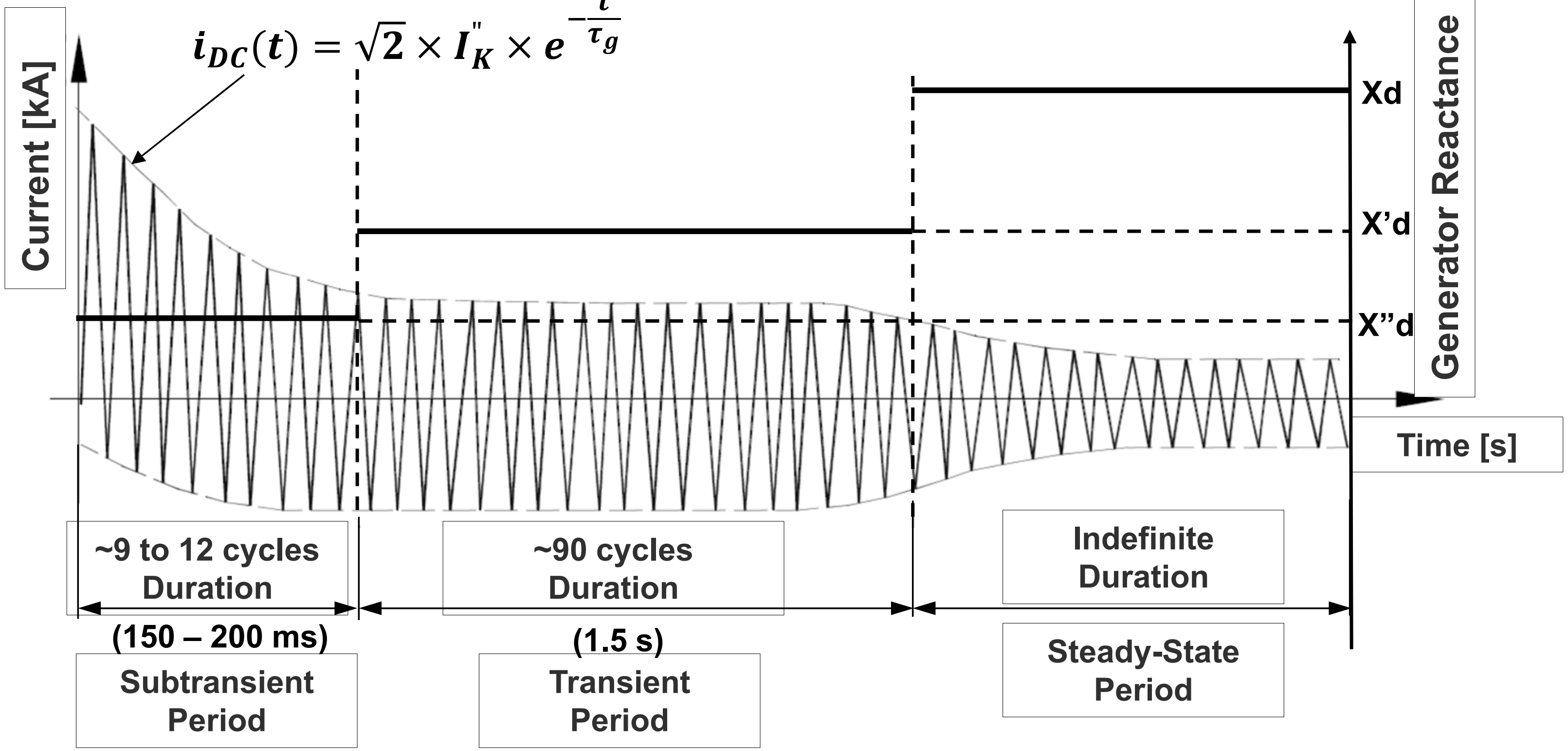
A BETTER UNDERSTANDING ON GENERATOR DECREMENT CURVE

- EQUATIONS FOR GENERATOR DECREMENT CURVE
- GENERATOR TIME CONSTANTS
- FIELD FORCING SETTING
- RELAY SENSIBILITION CHECK ON DIFFERENT VOLTAGE LEVEL OTHER THAN GENERATOR VOLTAGE LEVEL
- DECREMENT CURVE FOR 3-PHASE AND 1-PHASE FAULTS

SHORT CIRCUIT CURRENT DECAYS WITH TIME

Short circuit current decays with time. This variation depends on two types of decrement, AC and DC. DC decrement occurs during the first cycles of the short-circuit. AC decrement is divided in three different time periods known as subtransient, transient and steady-state, based respectively on the generator's reactance X"d, X'd and Xd. At generator's terminals this variation is quite pronounced.

$$i_{DC}(t) = \sqrt{2} \times I_K'' \times e^{-\frac{t}{\tau_g}}$$

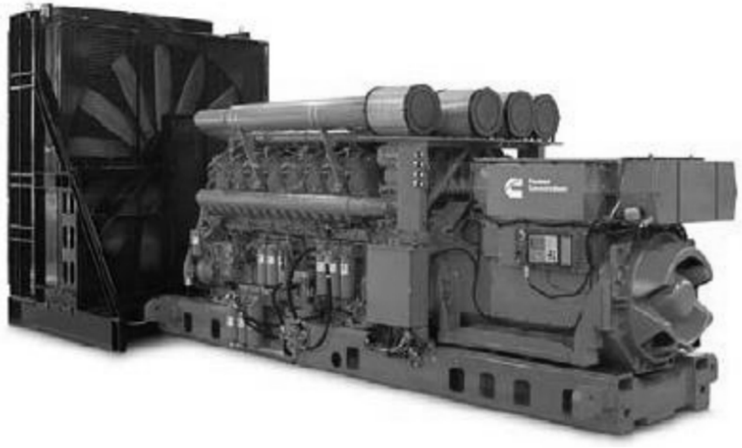


GENERATOR SHORT-CIRCUIT DECREMENT CURVE

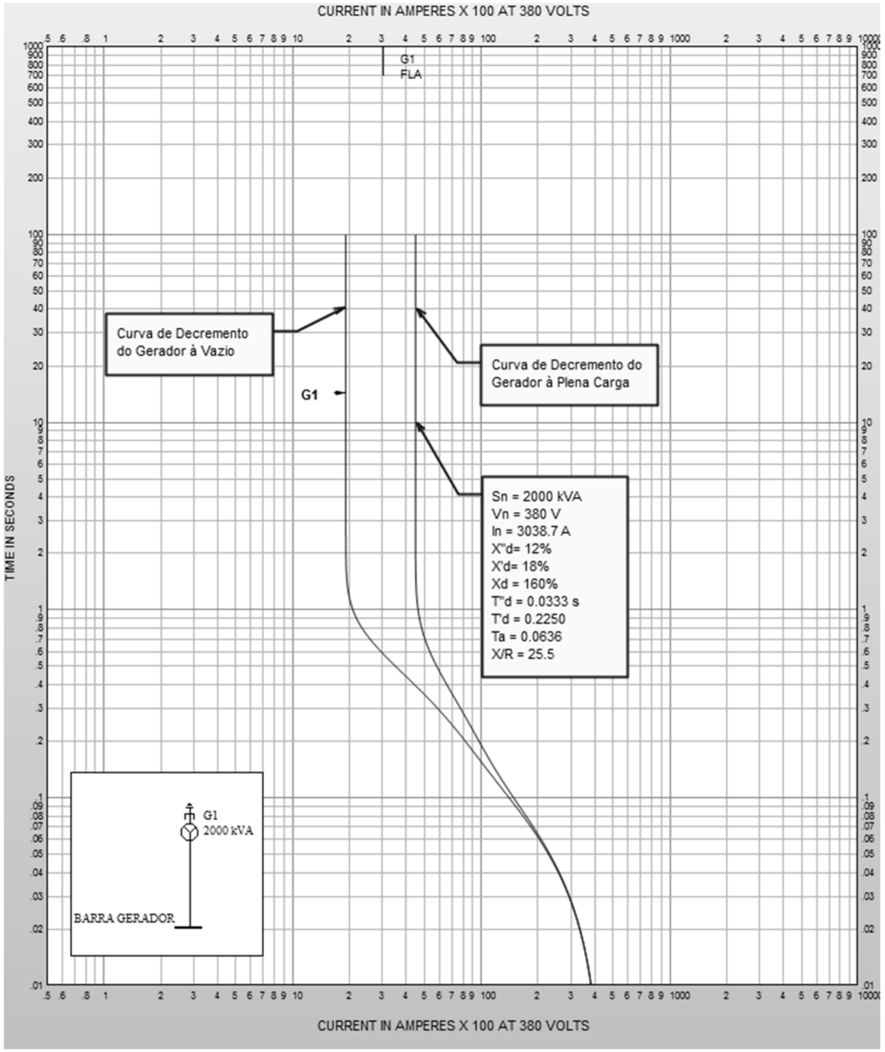
When a short-circuit occurs in an electrical system supplied by generators, the short-circuit current presents an initial peak and then begins to decay rapidly, since it does not have enough inertia to sustain the initial value permanently. In most cases the permanent short-circuit current may even be less than the generator full load amps. **This occurs when Xd is greater than 1pu**.

The short-circuit current value in this case depends on the generator loading. Thus, the actual value of the current depends on the loading and of the time. From no load condition to full load condition there are families of decrement curves.

In the next slide is present a such typical generator decrement curve. Nowadays, most of generators have a system that sustain the current value above the full load current for a specified time, **normally from 1.5 to 4 times FLA for 10s**, depending on the manufacturer.



GENERATOR SHORT-CIRCUIT DECREMENT CURVE



Short-circuit current decay with time is known as the **generator decrement curve**. AC component decay of the short circuit is presented in the equation below, as indicated in **IEEE Std 242**:

$$i_{ac} = (i_d'' - i_d')\varepsilon^{-t/T_d''} + (i_d' - i_d)\varepsilon^{-t/T_d'} + i_d$$

$$i_d'' = \frac{e''}{X_d''}\text{ pu} \qquad e'' = e_t + X_d''\sin\theta\text{ pu}$$

When machine is at no-load, $e'' = e_t$.

$$i_d' = \frac{e'}{X_d'}\text{ pu} \qquad e' = e_t + X_d'\sin\theta\text{ pu}$$

Again, at no-load, $e' = e_t$.

$$\sqrt{2}\, i_d''\varepsilon^{-t/T_A}$$

$$i_{tot} = \sqrt{i_{ac}^2 + i_{dc}^2}$$

$$i_d = \left(\frac{e_t}{X_d}\right)\left(\frac{I_F}{I_{Fg}}\right)$$

$$I_{K\_Forced} = I_K\left(\frac{I_F}{I_{Fg}}\right)$$

Where:

IF = Is the field current for na specified condition (pu)

IFg= Is the field current for no load condition at rated voltage (pu).

GENERATOR DECREMENT CURVE EQUATIONS

GENERATOR DECREMENT INSTANTANEOUS CURRENT

$$i_{AC}(t) = (I''_K - I'_K) \times e^{-\frac{t}{\tau''_d}} + (I'_K - I_K) \times e^{-\frac{t}{\tau'_d}} + I_K$$

Where:
I''_K= Subtransient Short-Circuit Current
I'_K= Transient Short-Circuit Current
I_K= Stead-state Short-Circuit Current
τ"d = Subtransient Time Constant
τ'd = Transient Time Constant
τ'g = Armature Time Constant

I''_K, I'_K and I_K are calculated as:

3-Phase →

$$I''_{K(3)} = \frac{E''_Y}{X''_d + Z_N} \qquad I'_{K(3)} = \frac{E'_Y}{X'_d + Z_N} \qquad I_{K(3)} = \frac{E_Y}{X_d + Z_N}$$

2-Phase →

$$I''_{K(2)} = \frac{\sqrt{3}E''_Y}{X''_d + X_2 + 2Z_N} \qquad I'_{K(2)} = \frac{\sqrt{3}E'_Y}{X'_d + X_2 + 2Z_N} \qquad I_{K(2)} = \frac{\sqrt{3}E_Y}{X_d + X_2 + 2Z_N}$$

1-Phase →

$$I''_{K(1)} = \frac{3E''_Y}{X''_d + X_2 + 2Z_N + Z_{N0} + X_0 + 3Z_G} \qquad I'_{K(1)} = \frac{3E'_Y}{X'_d + X_2 + 2Z_N + Z_{N0} + X_0 + 3Z_G} \qquad I_{K(1)} = \frac{3E_Y}{X_d + X_2 + 2Z_N + Z_{N0} + X_0 + 3Z_G}$$

$$E''_Y = U_Y + jX''_d.I \qquad E''_Y = k''.U_Y$$

$$E'_Y = U_Y + jX'_d.I \qquad E'_Y = k'.U_Y$$

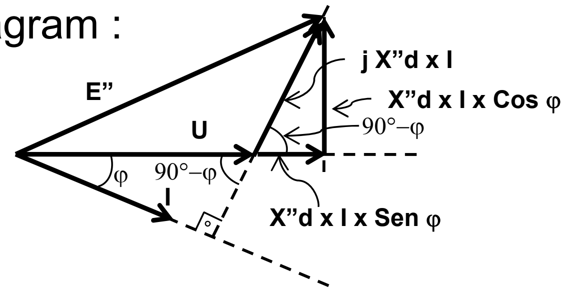
$$E_Y = U_Y + jX_d.I \qquad E_Y = k\ .U_Y$$

Where:
E''_Y= E.M.F. behind saturated d axis subtransient reactance
E'_Y= E.M.F. behind saturated d axis transient reactance
E_Y= E.M.F. behind synchronous reactance
X"d = Saturated d axis subtransient reactance
X'd = Saturated d axis transient reactance
Xd = Synchronous reactance
Z_N = Generator external impedance (up to point of application of the fault)
U_Y = Voltage at the generator's terminal
I = Generator loading current

GENERATOR DECREMENT CURVE EQUATIONS

E.M.F. Calculation

For cylindric rotor machines, the E.M.F. can be calculated based on the phasor diagram :



Based on the phasor diagram the following equations can be written:

$$E_Y'' = \sqrt{\left(U + X_d'' \times I_L \times \sin\varphi\right)^2 + \left(X_d'' \times I_L \times \cos\varphi\right)^2}$$

Analogously, these other two equations can be written:

$$E_Y' = \sqrt{(U + X_d' \times I_L \times \sin\varphi)^2 + (X_d' \times I_L \times \cos\varphi)^2}$$

$$E_Y = \sqrt{(U + X_d \times I_L \times \sin\varphi)^2 + (X_d \times I_L \times \cos\varphi)^2}$$

GENERATOR TIME CONSTANTS

Preferably, manufacturer data shall be used. When these data are not available time-constants can be calculated based on the equations:

$$\tau''_d = \frac{X''_d + X_N}{X'_d + X_N} . \tau''_{do}$$

$$\tau'_d = \frac{X'_d + X_N}{X_d + X_N} . \tau'_{do}$$

$$\tau_g = \frac{X''_d + X_N}{\omega(R_a + R_N)}$$

Below, some typical data for turbo-generators:

τ"do ~ 50 ms and is lower than τ'd, since X'd > X"d.

τ'do ~ (5 a 12) s – Lower values are for saliente pole machines. Higher values are normal in turbo-generators.

τ"d ~ 3 a 4 semi-cycles (for short-circuit at generator terminals).
X'd ~ 1.5 X"d

For short-circuit at generator terminals τ'd value decrease to 1s for turbo-generators and to 2s for salient pole machines.

GENERATOR DECREMENT CURVE EQUATIONS

DC component of short-circuit current is calculated by the equation:

$$i_{DC}(t) = \sqrt{2} \times I_K^{"} \times e^{-\frac{t}{\tau_g}}$$

The total **rms asymmetrical short-circuit current** is calculated as:

$$i_{TOTAL}(RMS) = \sqrt{i_{AC}(t)^2 + i_{DC}(t)^2}$$

$$i_{TOTAL}(RMS) = \sqrt{\left[\left(I_K^{"} - I_K'\right) \times e^{-\frac{t}{\tau_d^{"}}} + \left(I_K' - I_K\right) \times e^{-\frac{t}{\tau_d'}} + I_K\right]^2 + 2 \times \left[I_K^{"} \times e^{-\frac{t}{\tau_g}}\right]^2}$$

The above equation is presented in the book "**Short-circuit Currents in Three-phase Systems**" Written by Richard Roeper – Siemens – 1985, 167 pages.

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EXAMPLE

Determine the generator short-circuit current decrement curve for a 3400 kVA, 380V, 0.8 PF, rated current 5165.7 Amps, X"d = 15.8%, X'd = 21.4%, Xd = 290%, Ra = 0.5588%, T"do = 20.3ms, T'do=2.122s, for a short-circuit at its terminals (Zn = 0), at no-load and full load.

Generator Manufacturer Data	
Frequency (Hz)	60
TIF	< 50
Cooling Air (m3/s)	3.7
Voltage (L-L) (Y) (V)	380
Base kVA	3400
Base Rated Amps	5165.8
X"d (%)	15.8
X'd (%)	21.4
Xd (%)	290
X"q (%)	29.3
Xq (%)	195
XL (%)	9.4
X2 (%)	22.6
Xo (%)	2.9
T"d (s)	0.015
T'd (s)	0.19
T'do (s)	4.3
Tg (s)	0.075
SC Ratio	1/Xd

Solution

Calculation of the time constants T"d, T'd e Tg of the machine.

$$\tau_d'' = \frac{X_d'' + X_N}{X_d' + X_N} \times \tau_{d0}'' = \frac{0.158 + 0.0}{0.214 + 0.0} \times 0.0203 = 0.0150\ s$$

$$\tau_d' = \frac{X_d' + X_N}{X_d + X_N} \times \tau_{d0}' = \frac{0.214 + 0.0}{2.90 + 0.0} \times 2.1222 = 0.01566\ s$$

$$\tau_g = \frac{X_d'' + X_N}{\omega \times (R_a + R_N)} = \frac{0.15.8 + 0.0}{2\pi \times 60 \times (0.005588 + 0.0)} = 0.0750\ s$$

The e.m.f E''_Y, E'_Y and E_Y can be calculated:

$$E_Y'' = \sqrt{\left(U + X_d'' \times I \times Sen\varphi\right)^2 + \left(X_d'' \times I \times Cos\varphi\right)^2} = \sqrt{(1 + 0.158 \times 1 \times 0.6)^2 + (0.158 \times 1 \times 0.8)^2}$$

$$\boldsymbol{E_Y'' = \sqrt{1.2146} = 1.1021}$$

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GENERATOR DECREMENT CURVE EQUATIONS

EXAMPLE

Analogously,

$$E'_Y = \sqrt{(U + X'_d \times I \times Sen\varphi)^2 + (X'_d \times I \times Cos\varphi)^2} = \sqrt{(1 + 0.214 \times 1 \times 0.6)^2 + (0.214 \times 1 \times 0.8)^2}$$

$$\boldsymbol{E'_Y = \sqrt{1.3026} = 1.1413}$$

$$E_Y = \sqrt{(U + X_d \times I \times Sen\varphi)^2 + (X_d \times I \times Cos\varphi)^2} = \sqrt{(1 + 2.9 \times 1 \times 0.6)^2 + (2.9 \times 1 \times 0.8)^2}$$

$$\boldsymbol{E_Y = \sqrt{12.89} = 3.5903}$$

The short-circuit currents can be determined:

$$I''_K = \frac{E''_Y}{X''_d + Z_N} = \frac{1.1021}{0.158 + 0.0} = 6.9751\,pu \qquad I''_K = 6.9751 \times 5165.7 = 36032\,A$$

$$I'_K = \frac{E'_Y}{X'_d + Z_N} = \frac{1.1413}{0.214 + 0.0} = 5.3332\,pu \qquad I'_K = 5.3332 \times 5165.7 = 27050\,A$$

$$I_K = \frac{E_Y}{X_d + Z_N} = \frac{3.5903}{2.9 + 0.0} = 1.238\,pu \qquad I_K = 1.238 \times 5165.7 = 6395.3\,A$$

Applying the calculated values into the equation below, a table just like the one presented in the next slide can be assembled:

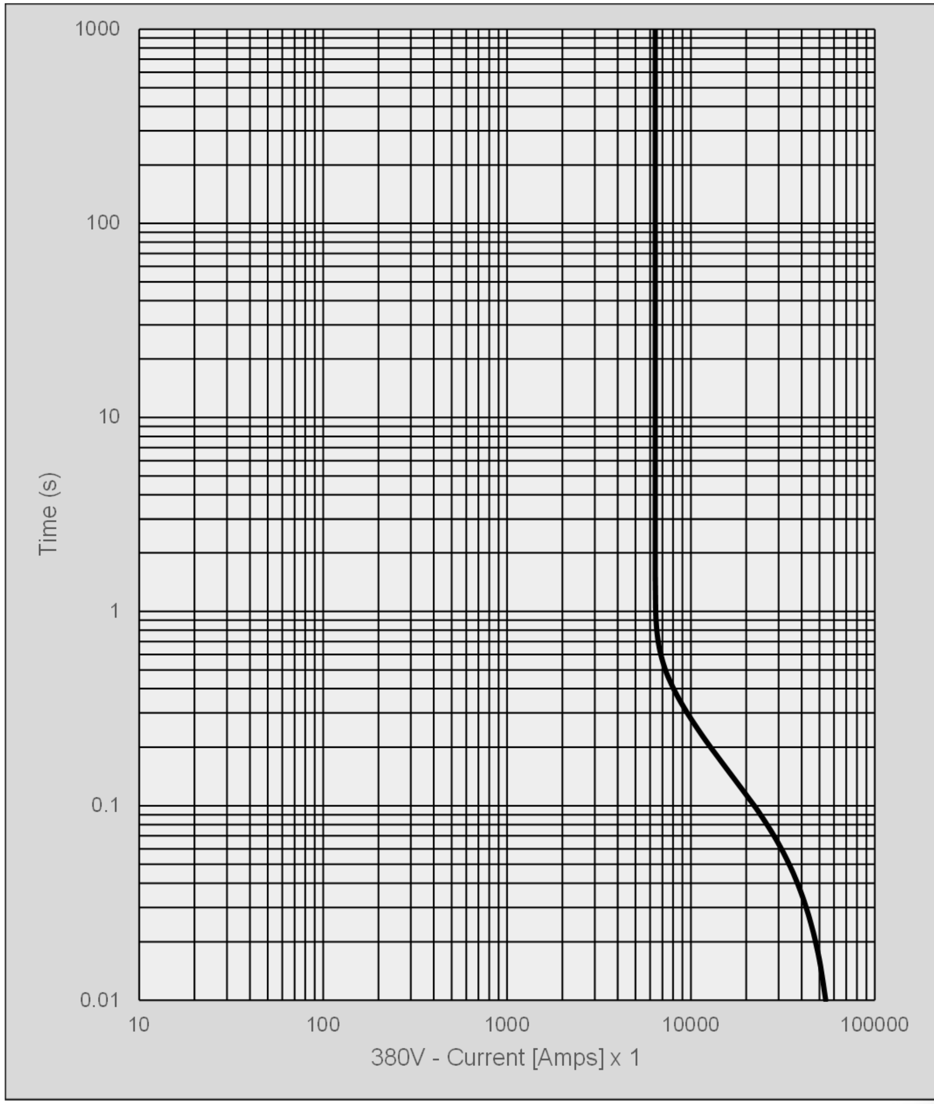
$$i_{TOTAL}(RMS) = \sqrt{\left[\left(I''_K - I'_K\right) \times e^{-\frac{t}{\tau''_d}} + (I'_K - I_K) \times e^{-\frac{t}{\tau'_d}} + I_K\right]^2 + 2\left(I''_K \times e^{-\frac{t}{\tau_g}}\right)^2}$$

GENERATOR DECREMENT CURVE EQUATIONS

Simulating the generator data based on showed equations in a spreadsheet you can table and plot it for **full load condition**.

Tempo	Iac	Idc	Itotal	Tempo	Iac	Idc	Itotal	Tempo	Iac	Idc	Itotal
0.01	30596.64	44596.11	54082.97	0.6	6853.791	17.0943	6853.812	35	6395.333	1.1E-198	6395.333
0.015	28738.57	41719.97	50660.26	0.7	6637.406	4.506015	6637.408	40	6395.333	1.2E-227	6395.333
0.02	27249.95	39029.33	47600.93	0.8	6523.152	1.187775	6523.152	45	6395.333	1.4E-256	6395.333
0.025	26031.02	36512.21	44841.45	0.9	6462.823	0.313095	6462.823	50	6395.333	1.5E-285	6395.333
0.03	25010.11	34157.43	42334.81	1	6430.969	0.082531	6430.969	60	6395.333	0	6395.333
0.035	24135.74	31954.52	40045.29	1.5	6396.795	0.000105	6396.795	70	6395.333	0	6395.333
0.04	23370.86	29893.68	37945.08	2	6395.393	1.34E-07	6395.393	80	6395.333	0	6395.333
0.045	22688.79	27965.75	36012	2.5	6395.335	1.7E-10	6395.335	90	6395.333	0	6395.333
0.05	22070.27	26162.15	34227.99	3	6395.333	2.16E-13	6395.333	100	6395.333	0	6395.333
0.06	20971.96	22896.42	31049.46	3.5	6395.333	2.76E-16	6395.333	150	6395.333	0	6395.333
0.07	20004.14	20038.34	28314.32	4	6395.333	3.51E-19	6395.333	200	6395.333	0	6395.333
0.08	19128.32	17537.03	25950.72	4.5	6395.333	4.46E-22	6395.333	250	6395.333	0	6395.333
0.09	18323.17	15347.94	23901.84	5	6395.333	5.68E-25	6395.333	300	6395.333	0	6395.333
0.1	17576.31	13432.11	22121.21	6	6395.333	9.2E-31	6395.333	350	6395.333	0	6395.333
0.15	14512.5	6896.28	16067.71	7	6395.333	1.49E-36	6395.333	400	6395.333	0	6395.333
0.2	12293.39	3540.671	12793.11	8	6395.333	2.41E-42	6395.333	450	6395.333	0	6395.333
0.25	10681.13	1817.843	10834.72	9	6395.333	3.91E-48	6395.333	500	6395.333	0	6395.333
0.3	9509.598	933.3124	9555.288	10	6395.333	6.33E-54	6395.333	600	6395.333	0	6395.333
0.35	8658.307	479.1789	8671.556	15	6395.333	7.05E-83	6395.333	700	6395.333	0	6395.333
0.4	8039.718	246.0189	8043.481	20	6395.333	7.9E-112	6395.333	800	6395.333	0	6395.333
0.45	7590.222	126.3104	7591.273	25	6395.333	8.8E-141	6395.333	900	6395.333	0	6395.333
0.5	7263.596	64.84998	7263.886	30	6395.333	9.8E-170	6395.333	1000	6395.333	0	6395.333

Note: Time in seconds and currents in Amps.



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GENERATOR DECREMENT CURVE EQUATIONS

For the **no load condition** $E''_Y = E'_Y = E_Y = 1$
The short circuit currents will be determined as:

$$I''_K = 6.3291 \times 5165.7 = 32695\ A$$

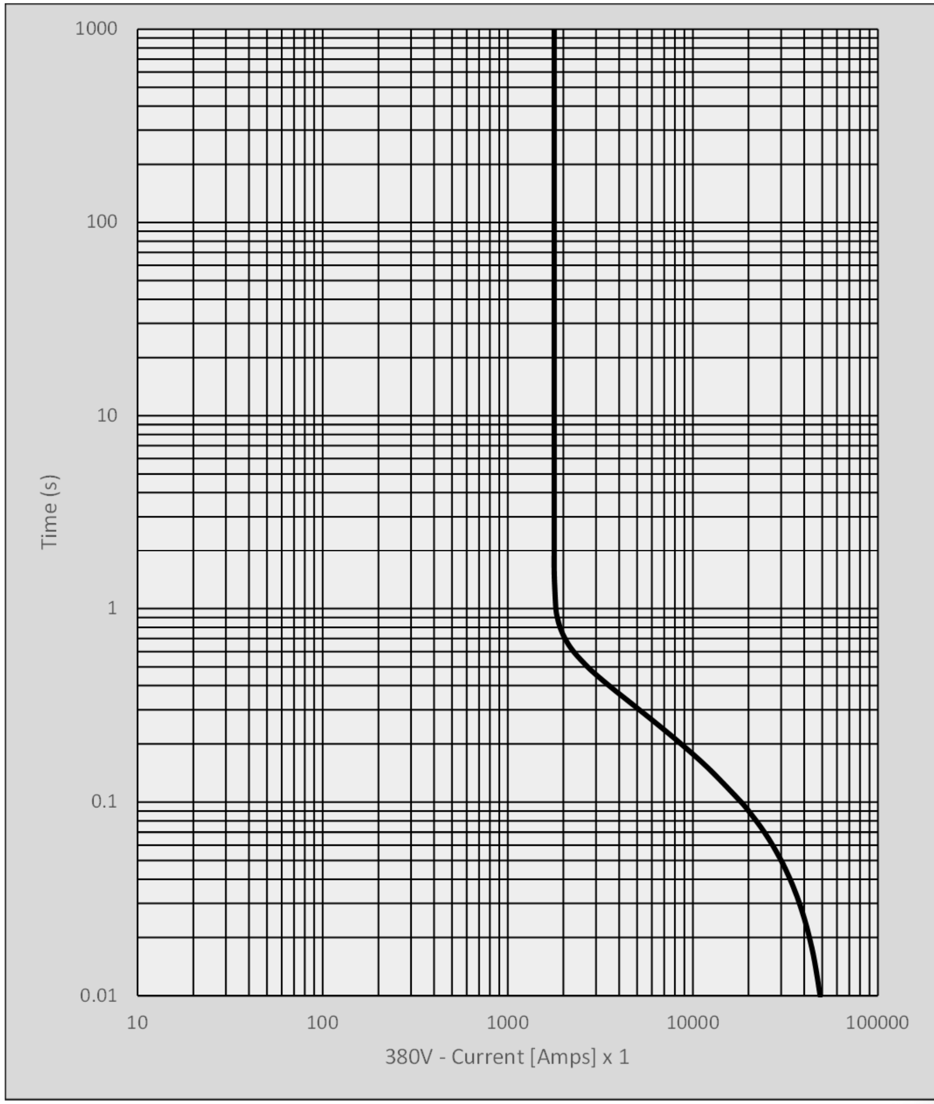
$$I'_K = 4.6729 \times 5165.7 = 24139\ A$$

$$I_K = 0.3448 \times 5165.7 = 1781.3\ A$$

Simulating these values, the spreadsheet below can be plot it.

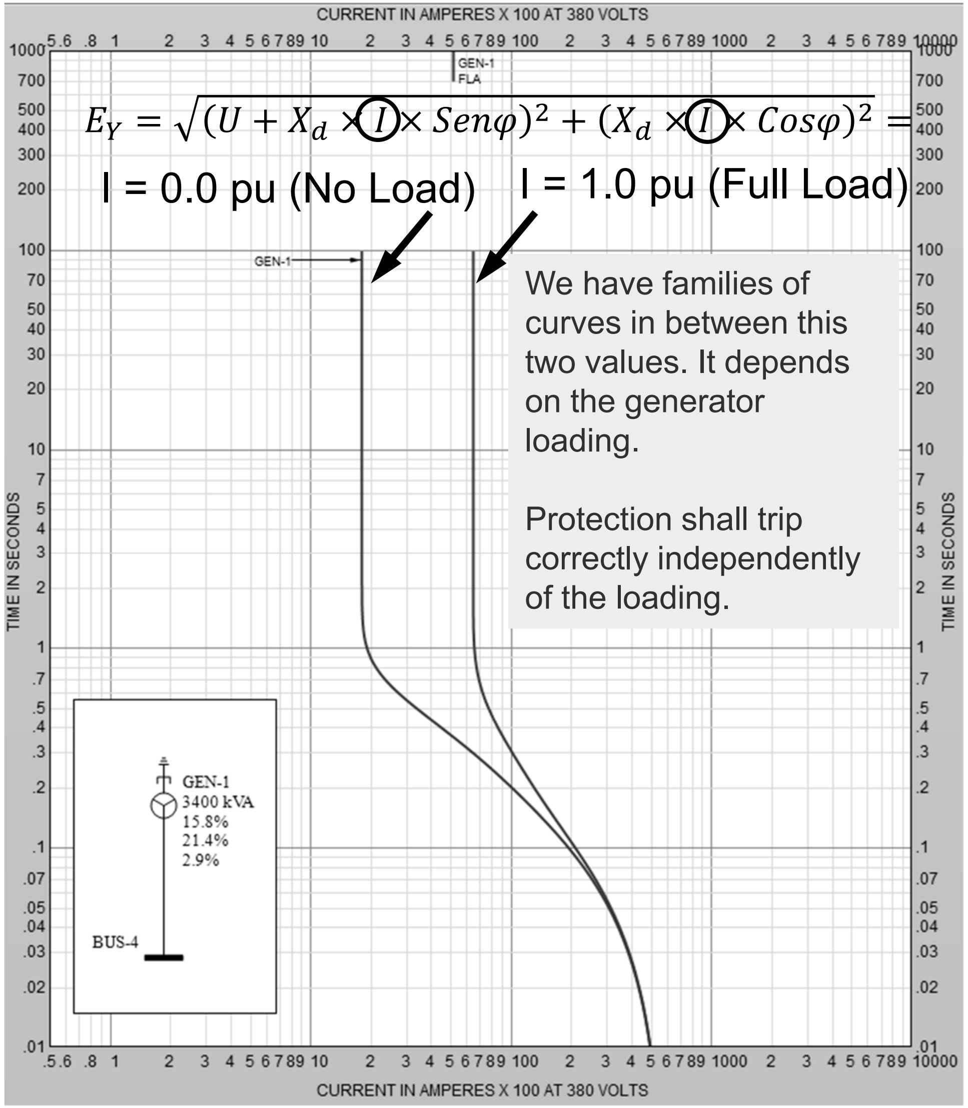
Tempo	Iac	Idc	Itotal	Tempo	Iac	Idc	Itotal	Tempo	Iac	Idc	Itotal
0.01	27149.02	40465.67	48729.25	0.6	2265.824	15.51104	2265.877	35	1781.298	9.9E-199	1781.298
0.015	25244.72	37855.92	45501.28	0.7	2037.136	4.088674	2037.14	40	1781.298	1.1E-227	1781.298
0.02	23714.05	35414.48	42620.9	0.8	1916.385	1.077764	1916.386	45	1781.298	1.2E-256	1781.298
0.025	22456.31	33130.5	40023.94	0.9	1852.627	0.284096	1852.627	50	1781.298	1.4E-285	1781.298
0.03	21399.22	30993.81	37663.55	1	1818.961	0.074887	1818.961	60	1781.298	0	1781.298
0.035	20490.81	28994.93	35504.64	1.5	1782.844	9.53E-05	1782.844	70	1781.298	0	1781.298
0.04	19693.67	27124.96	33520.2	2	1781.362	1.21E-07	1781.362	80	1781.298	0	1781.298
0.045	18980.86	25375.6	31689.02	2.5	1781.301	1.54E-10	1781.301	90	1781.298	0	1781.298
0.05	18332.93	23739.05	29993.98	3	1781.299	1.96E-13	1781.299	100	1781.298	0	1781.298
0.06	17179.26	20775.79	26958.49	3.5	1781.298	2.5E-16	1781.298	150	1781.298	0	1781.298
0.07	16160.06	18182.42	24325.86	4	1781.298	3.18E-19	1781.298	200	1781.298	0	1781.298
0.08	15236.3	15912.77	22030.91	4.5	1781.298	4.05E-22	1781.298	250	1781.298	0	1781.298
0.09	14386.34	13926.43	20022.79	5	1781.298	5.15E-25	1781.298	300	1781.298	0	1781.298
0.1	13597.5	12188.04	18260.35	6	1781.298	8.35E-31	1781.298	350	1781.298	0	1781.298
0.15	10359.98	6257.556	12103.15	7	1781.298	1.35E-36	1781.298	400	1781.298	0	1781.298
0.2	8014.711	3212.739	8634.656	8	1781.298	2.19E-42	1781.298	450	1781.298	0	1781.298
0.25	6310.784	1649.476	6522.789	9	1781.298	3.55E-48	1781.298	500	1781.298	0	1781.298
0.3	5072.639	846.8701	5142.845	10	1781.298	5.74E-54	1781.298	600	1781.298	0	1781.298
0.35	4172.944	434.798	4195.535	15	1781.298	6.4E-83	1781.298	700	1781.298	0	1781.298
0.4	3519.183	223.2329	3526.256	20	1781.298	7.1E-112	1781.298	800	1781.298	0	1781.298
0.45	3044.128	114.6117	3046.285	25	1781.298	7.9E-141	1781.298	900	1781.298	0	1781.298
0.5	2698.931	58.84365	2699.572	30	1781.298	8.9E-170	1781.298	1000	1781.298	0	1781.298

Note: Time in seconds and currents in Amps.



GENERATOR DECREMENT CURVE EQUATIONS

Using now EasyPower, the values match with the spreadsheet.Without field forcing at no load, the generator decrement current would have the curve decay showed in the Figure. As can be seen, the steady-state sc current (sustained current) is below the generator rated current:
(1781 A < 5165 A!)



$$E_Y = \sqrt{(U + X_d \times I \times Sen\varphi)^2 + (X_d \times I \times Cos\varphi)^2} =$$

$$E_Y = \sqrt{(1 + 2.9 \times 1 \times 0.6)^2 + (2.9 \times 1 \times 0.8)^2}$$

$$\boldsymbol{E_Y = \sqrt{12.89} = 3.59}$$

$$I_K = \frac{E_Y}{X_d} = \frac{3.59}{2.9} = 1.238\,pu$$

$$I_K = I_{K\_for\_FLA} = 1.238 \times 5165.7 = 6395\,A$$

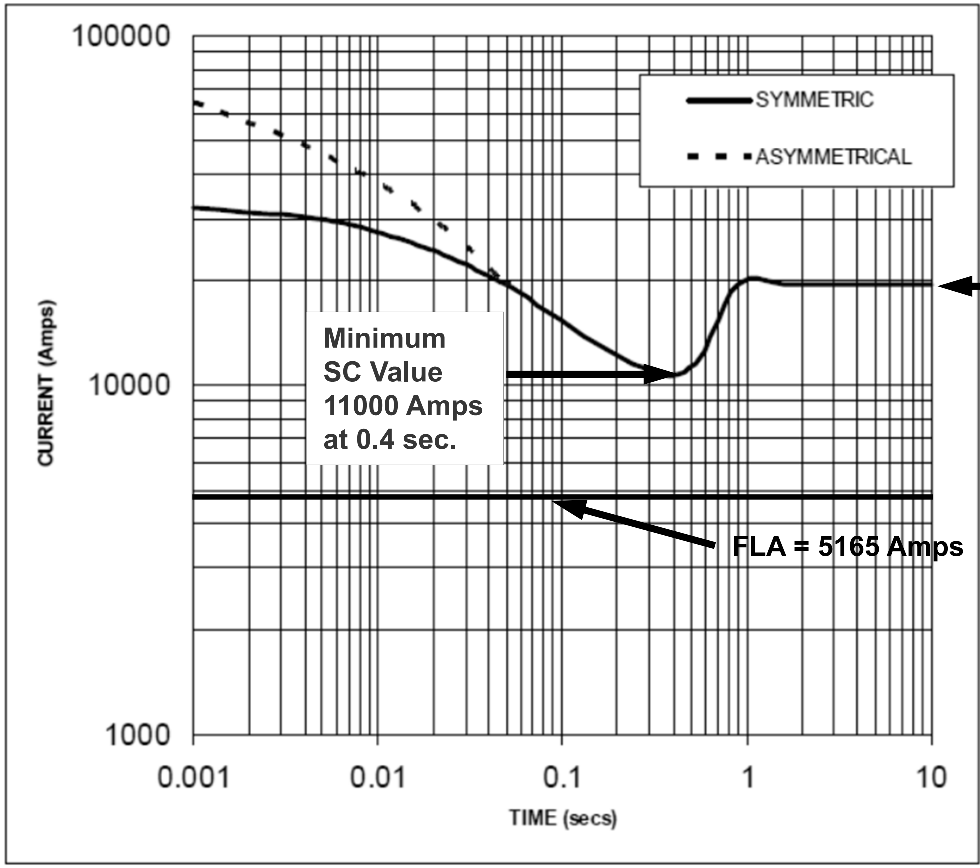
The steady-state current reaches just 23.8% over the full load (6395 / 5165 * 100).

FIELD FORCING SETTING

Three Phase Short Circuit Decrement Curve
No- Load Excitation at Rated Speed

Based on series star (wye) connection

As seen before the steady-state short circuit current of a generator depends on generator load and this current may be lower than its rated current. Nowadays, generator can be supplied with a field forcing current (sustained SC current) to keep the current over the rated current for a specified time, normally 10s for 3-ph SC.



NOTE 1

THE FOLLOWING MULTIPLICATION FACTORS SHOULD BE USED TO ADJUST THE VALUES FROM CURVES BETWEEN THE 0.001 SECONDS AND THE MINIMUM CURRENT POINT IN RESPECT OF NOMINAL OPERATING VOLTAGE

VOLTAGE	FACTOR
380V	X 1.00

kVA = 3400
kVrated = 0.38
Irated = 5165 A

19372 Amps

THE SUSTAINED CURRENT VALUE IS CONSTANT IRRESPECTIVE OF VOLTAGE LEVEL

NOTE 2
THE FOLLOWING MULTIPLICATION FACTORS SHOULD BE USED TO CONVERT THE VALUES CALCULATED IN ACCORDANCE WITH NOTE 1 TO THOSE APPLICABLE TO THE VARIOUS TYPES OF SHORT CIRCUIT

	3 PHASE	2 PHASE L-L	1 PHASE L-N
INSTANTANEOUS	X 1.0	X 0.87	X 1.30
MINIMUM	X 1.0	X 1.80	X 3.20
SUSTAINED	X 1.0	X 1.50	X 2.50
MAX SUSTAINED DURATION	10 SEC	5 SEC	2 SEC

ALL OTHER TIMES ARE UNCHANGED

SUSTAINED SHORT CIRCUIT = 19372 Amps

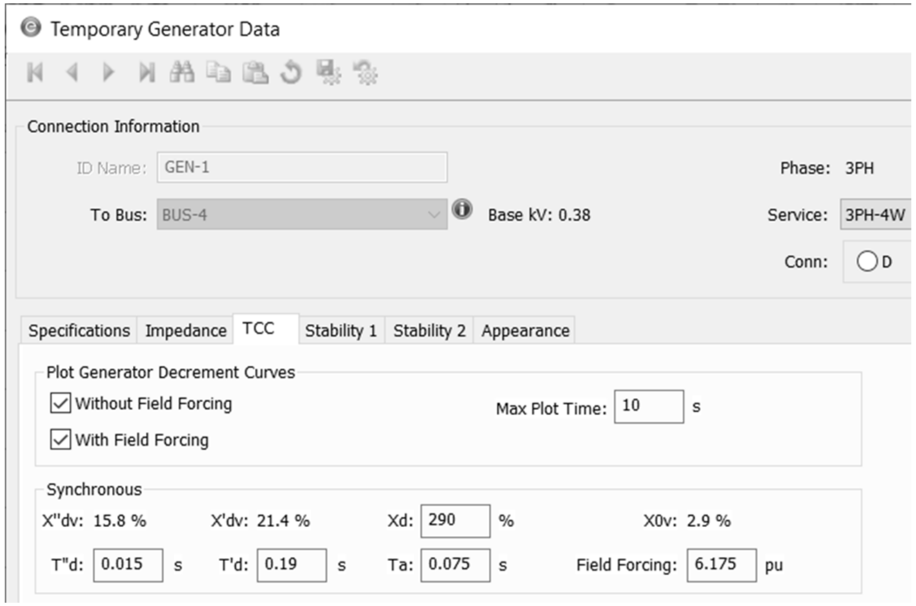
FIELD FORCING SETTING

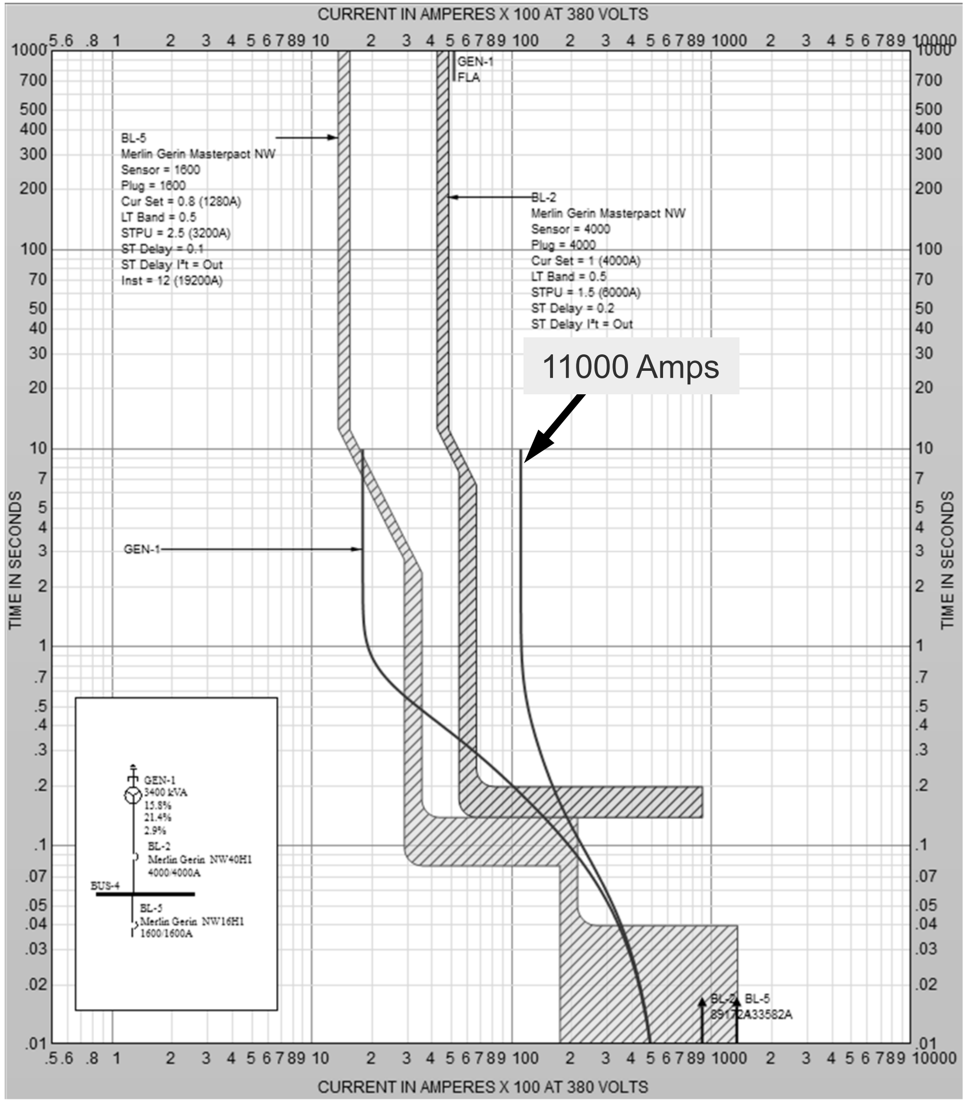
Setting up the Field Forcing Parameter for minimum current

The minimum SC current is 11000 Amps.
Field_Forcing for the rated current is 3.59

$$Field\_Forcing\_Adjust = \frac{I_{Desired}}{I_{K_{for\_FLA}}} = \frac{11000}{6395} = 1.72$$

$$New\_Field\_Forcing = 3.59 \times 1.72 = 6.175$$





FIELD FORCING SETTING

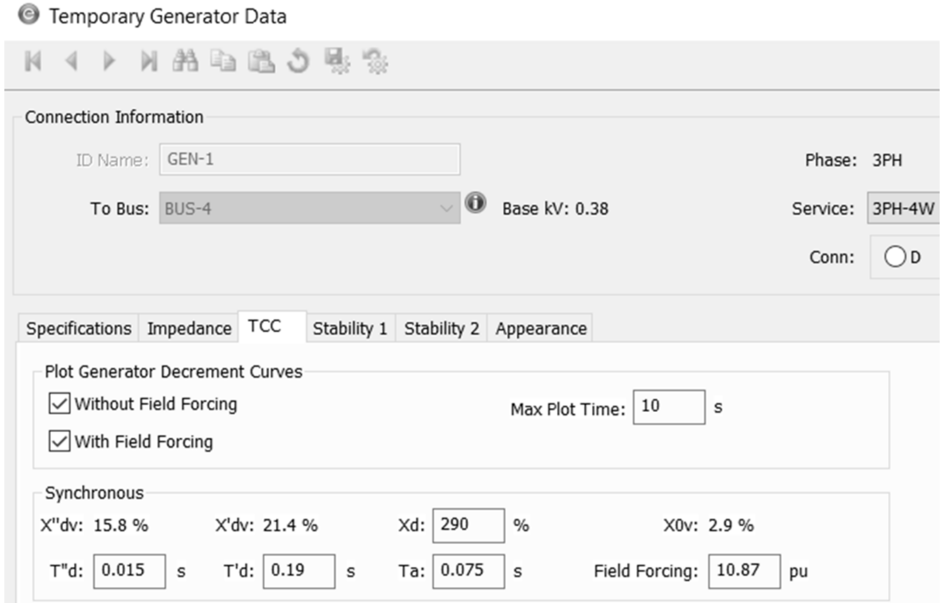
Setting up for the manufacturer sustained current of 19372 Amps.

Field_Forcing for the rated current is 3.59

$$Field_{Forcing_{Adjust}} = 3.59(1\,pu) * 19372/6395 =$$

$$Field_{Forcing_{Adjust}} = 3.59(1\,pu) * 3.02 =$$

$$New\_Field\_Forcing = 10.87$$


Temporary Generator Data

Connection Information

ID Name: GEN-1 | Phase: 3PH
To Bus: BUS-4 | Base kV: 0.38 | Service: 3PH-4W
Conn: D

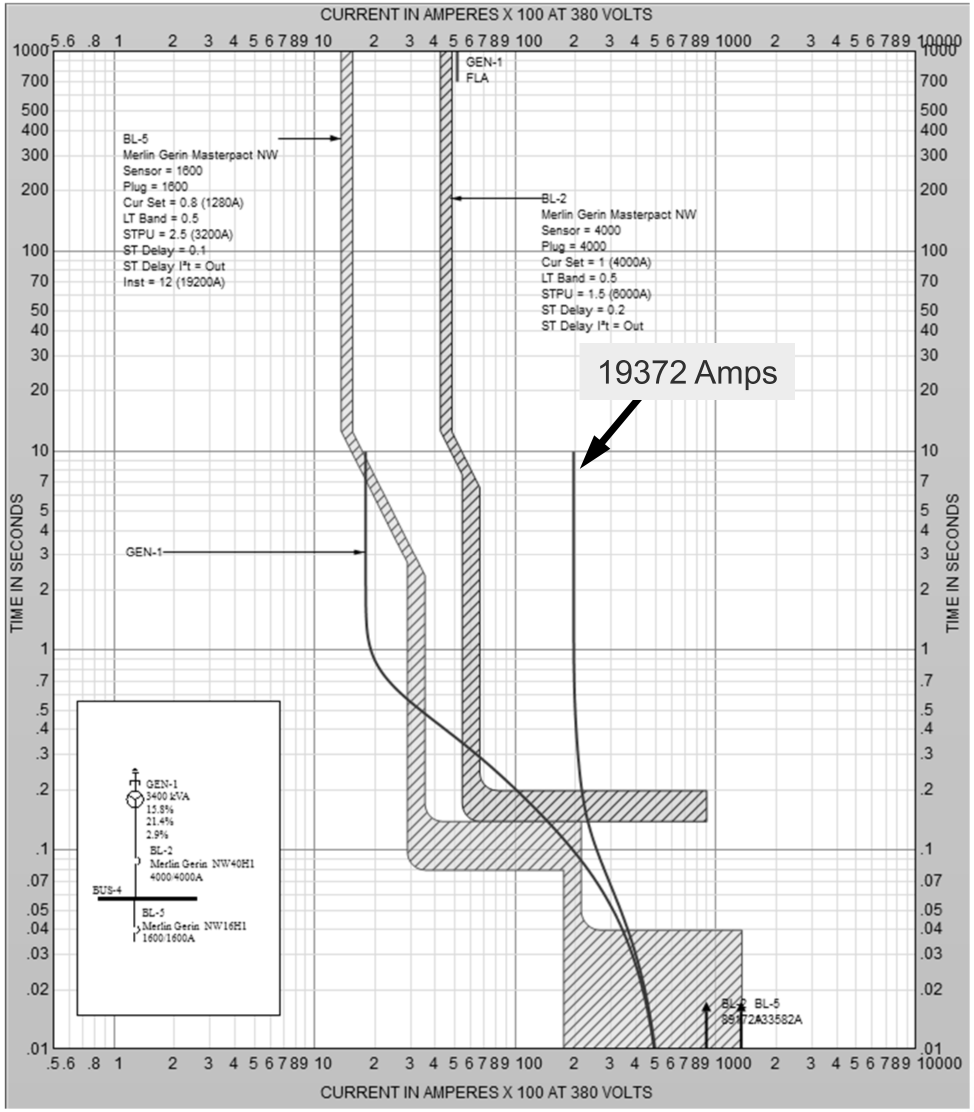
Specifications | Impedance | TCC | Stability 1 | Stability 2 | Appearance

Plot Generator Decrement Curves
- [x] Without Field Forcing
- [x] With Field Forcing

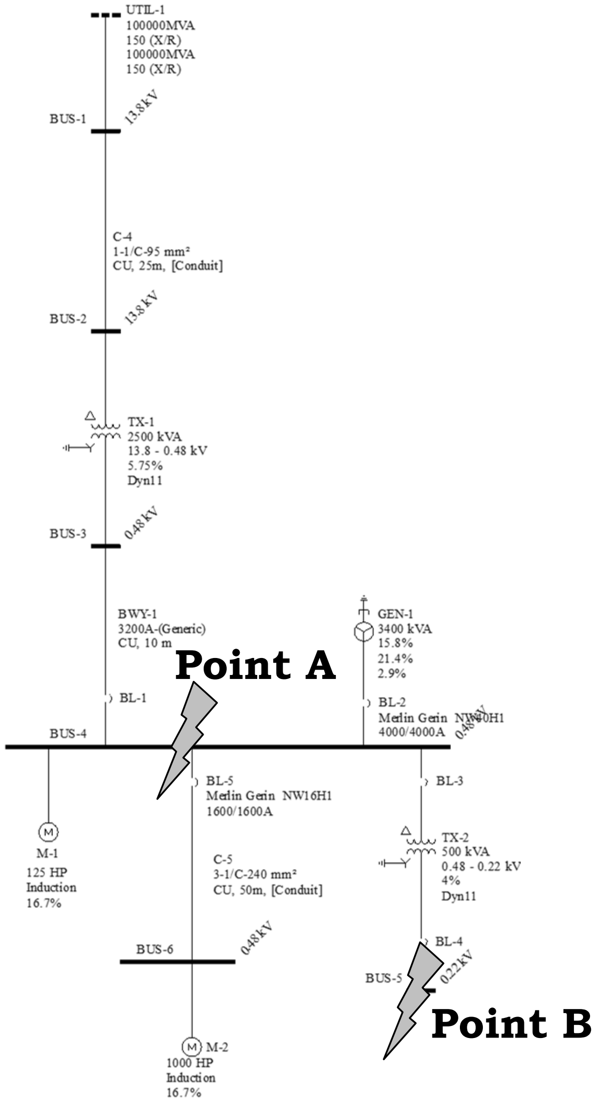
Max Plot Time: 10 s

Synchronous

X"dv: 15.8 % | X'dv: 21.4 % | Xd: 290 % | X0v: 2.9 %
T"d: 0.015 s | T'd: 0.19 s | Ta: 0.075 s | Field Forcing: 10.87 pu



DECREMENT CURVE FOR OTHER VOLTAGE LEVELS



DECREMENT CURVE FOR OTHER VOLTAGE LEVELS

Let us apply a fault at 220 V level. First of all, we must set the impedances of the transformer on the generator base.

$$Z\%_{TR\_B\_GE} = Z\%_{TR} \cdot \frac{MVA_{Gerador}}{MVA_{Transformador}}$$

$$Z\%_{TR\_B\_GE} = 4 \cdot \frac{3.4}{0.3} = 4 \cdot 11.33 = 45.33$$

X/R_TR_0.3 MVA = 3.68288
Angle = Arctg(3.68288) = 74.81º
ZTR_B_Ger = 45.33 ∠ 74.81°
ZTR_B_Ger = 11.879091 +j 43.749266
RN = 11.879091%   XN = 43.749266

This impedance shall be added to the generator's impedance, as follow:

X"d(%) = 15.8
X"d_New = 15.8+43.749266 = 59.549266
X'd (%) = 21.4
X'd _New = 18+43.749266 = 65.149266
Xd (%) = 290
Xd _New = 290+43.749266 = 333.749266

The new time constants change to:

RN = 11.879091%   XN = 43.749266

$$\tau_d'' = \frac{X_d'' + X_N}{X_d' + X_N} \cdot \tau_{d0}'' = \frac{15.8 + 43.749266}{21.4 + 43.749266} \cdot 0.02032 = \frac{59.549266}{65.149266} \cdot 0.02032$$

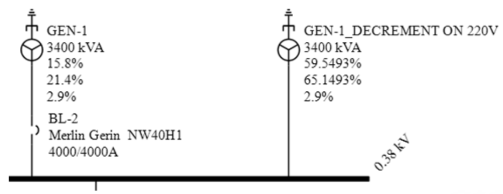
$$\tau_d'' = 0.018573s$$

$$\tau_d' = \frac{X_d' + X_N}{X_d + X_N} \cdot \tau_{d0}' = \frac{21.4 + 43.749266}{290 + 43.749266} \cdot 2.12196 = \frac{65.149266}{333.749266} \cdot 2.12196$$

$$\tau_d' = 0.4142s$$

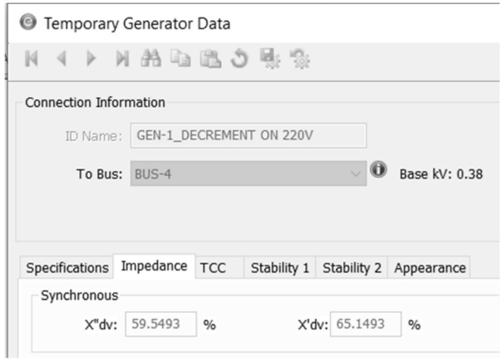
$$\tau_g = \frac{X_d'' + X_N}{\omega \cdot (R_a + R_N)} = \frac{15.8 + 43.749266}{377 \cdot (0.55881 + 11.879091)} = \frac{59.549266}{4688.978} = 0.0127s$$

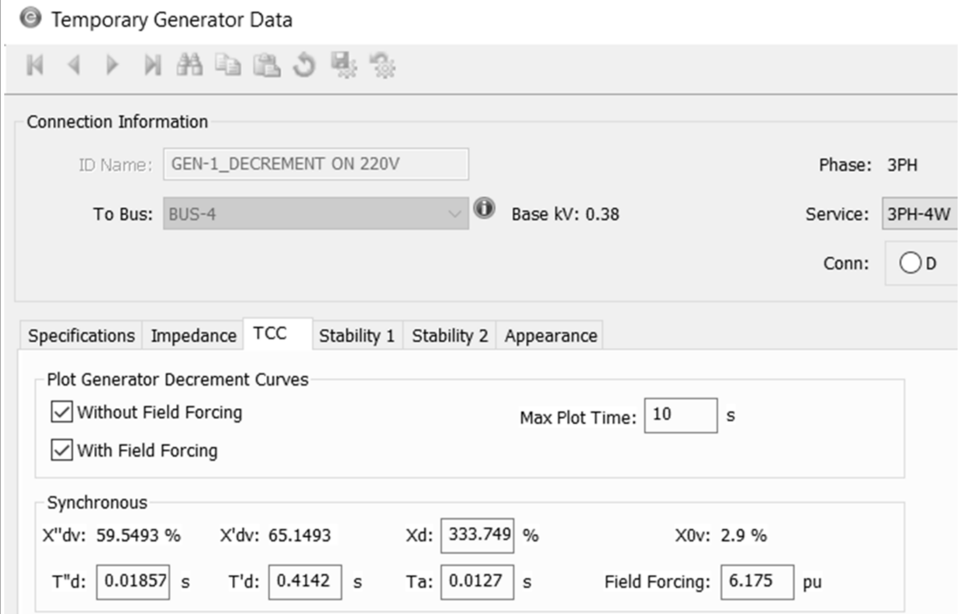
We have to duplicate the generator element and change these new calculated values replacing the old ones.

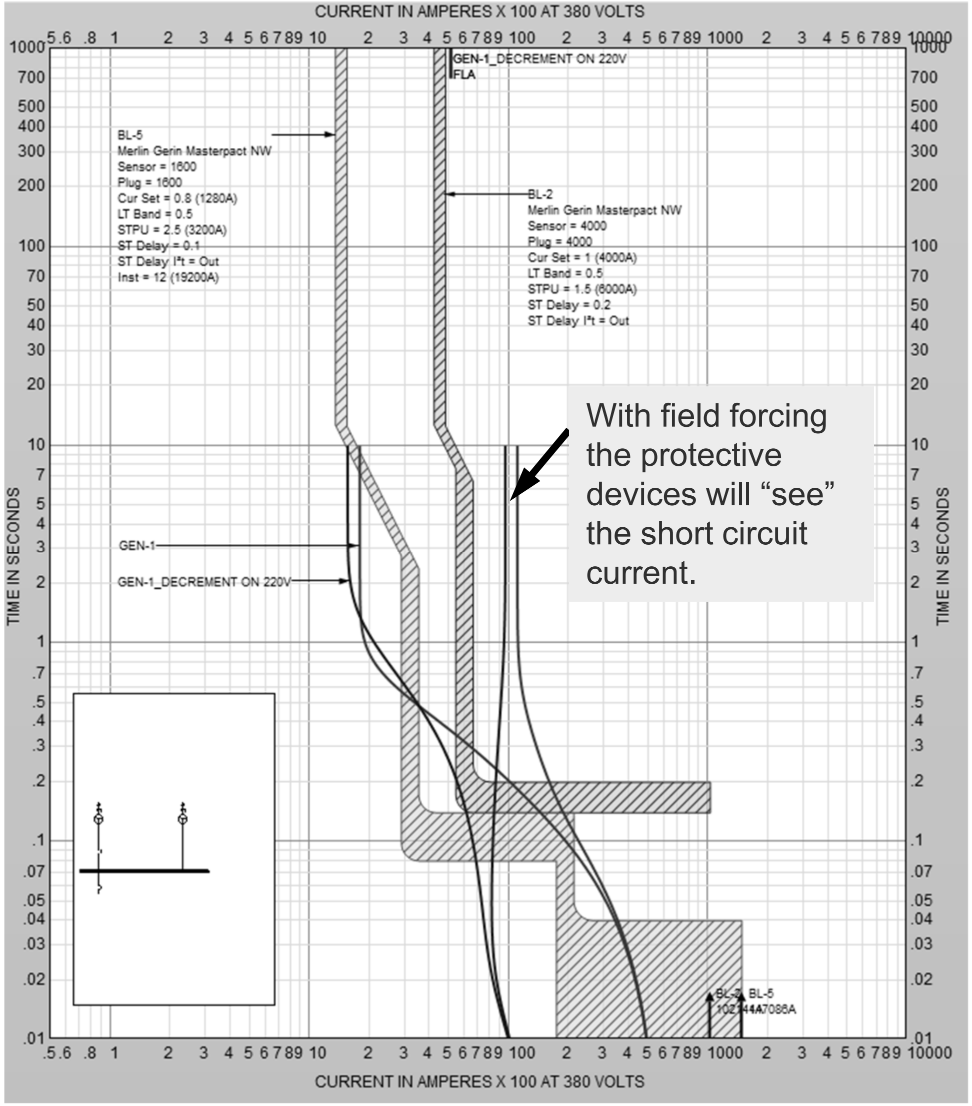


DECREMENT CURVE FOR OTHER VOLTAGE LEVELS

Correcting the impedances and time constants the new TCC is presented in the Figure.







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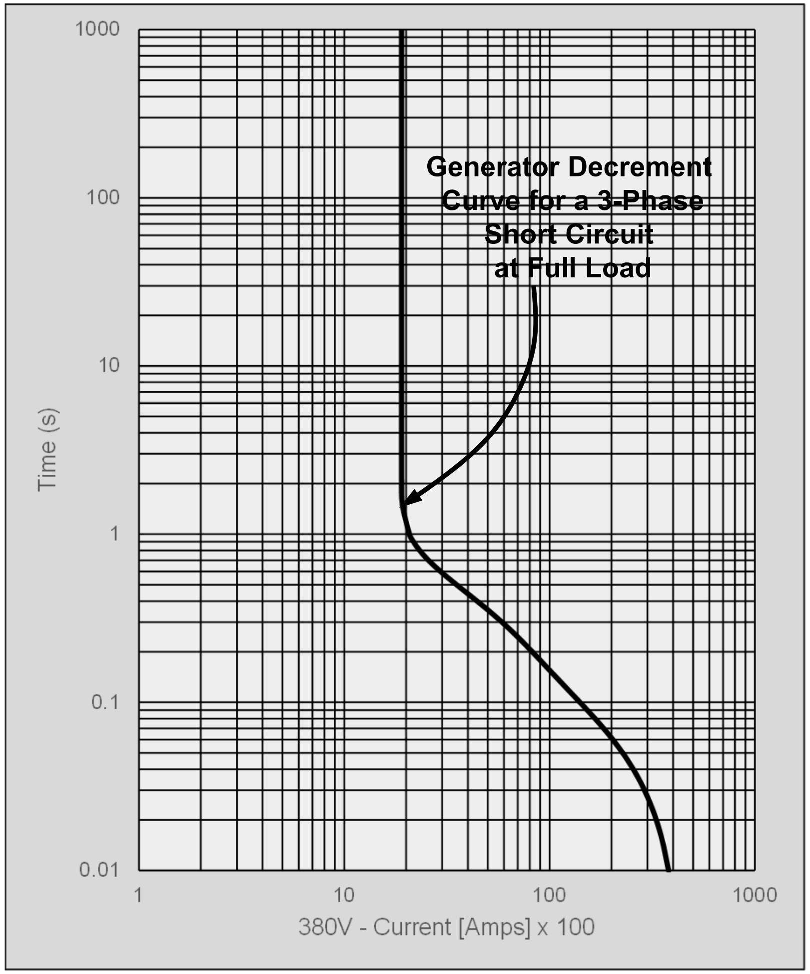
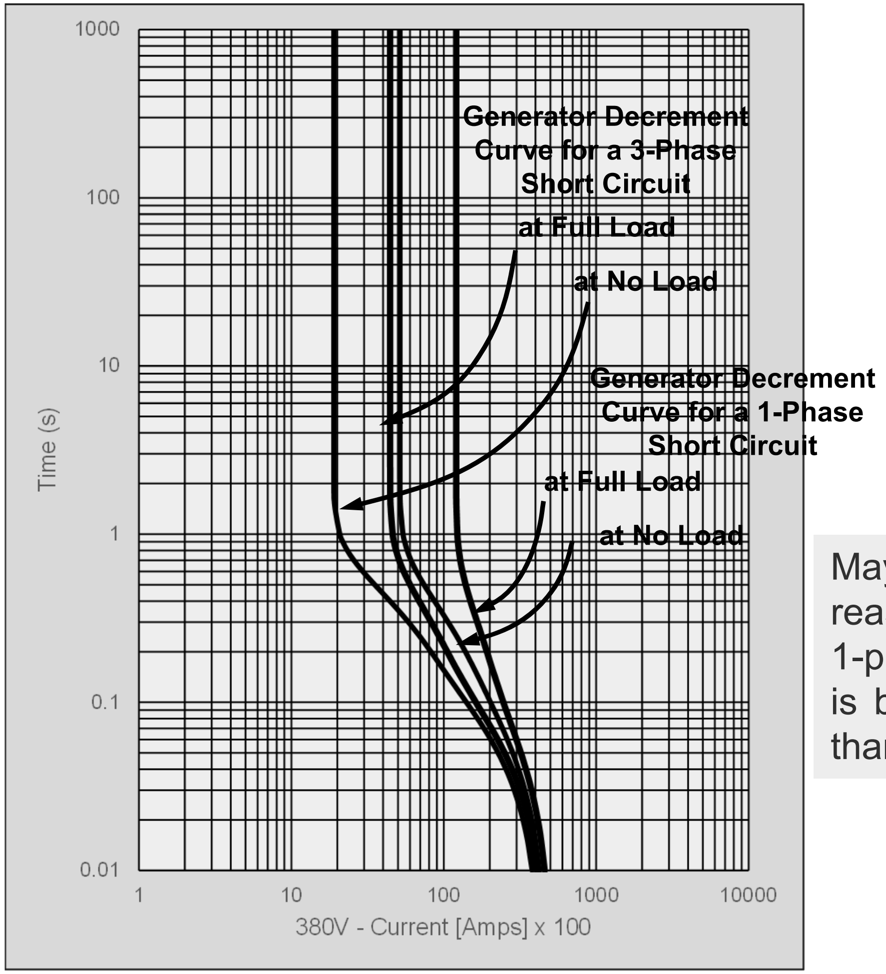
DECREMENT CURVE FOR DIFFERENT TYPES OF FAULTS

EXAMPLE





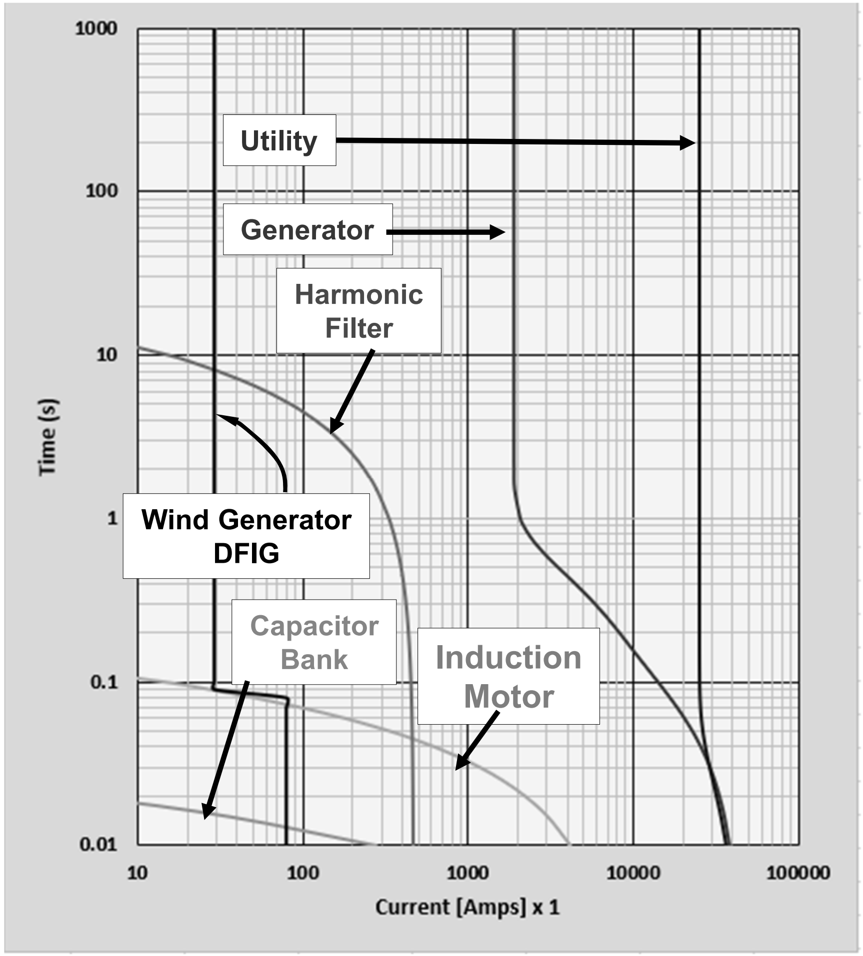
May be one the reasons for no plotting 1-ph decrement curve is because it is greater than the 3-phase.

4 - OVERCURRENT COORDINATION

- SHORT CIRCUIT CURRENTS CONTRIBUTIONS AT TCC FOR DIFFERENT SOURCES
- WHAT CURRENTS SHALL BE USED FOR COORDINATION
- WHERE TO APPLY THE COORDINATION TIME INTERVAL
- THE IMPORTANCE OF CONSIDERING THE 3-PHASE AND AND 1-PHASE ARCING CURRENT WHEN PERFORMING COORDINATION STUDIES
- OVERCURRENT COORDINATION BETWEEN TWO SERIES IEDS
- PERFORMING OVERCURRENT COORDINATION AND ARC FLASH STUDIES JUST IN TIME
- LOGICAL COORDINATION

SHORT CIRCUIT CURRENTS CONTRIBUTIONS AT TCC FOR DIFFERENT SOURCES

This slide was created to show the behavior for different sources short-circuit contributions.



WHAT CURRENTS SHALL BE USED FOR OVERCURRENT COORDINATION ?

The best reply to this question is: Is the current that each protective device "sees".
All possibilities shall be checked.

Types of current:

- 3-phase bolted short circuit current (for phase coordination)
- 3-phase arcing fault (for phase coordination)
- Single line-to-ground bolted short circuit current (for ground coordination)
- Capacitive (snubbers) and Charging Current (for ground coordination)
- Single line-to-ground arcing fault (for ground coordination)

Delayed or Instantaneous Current

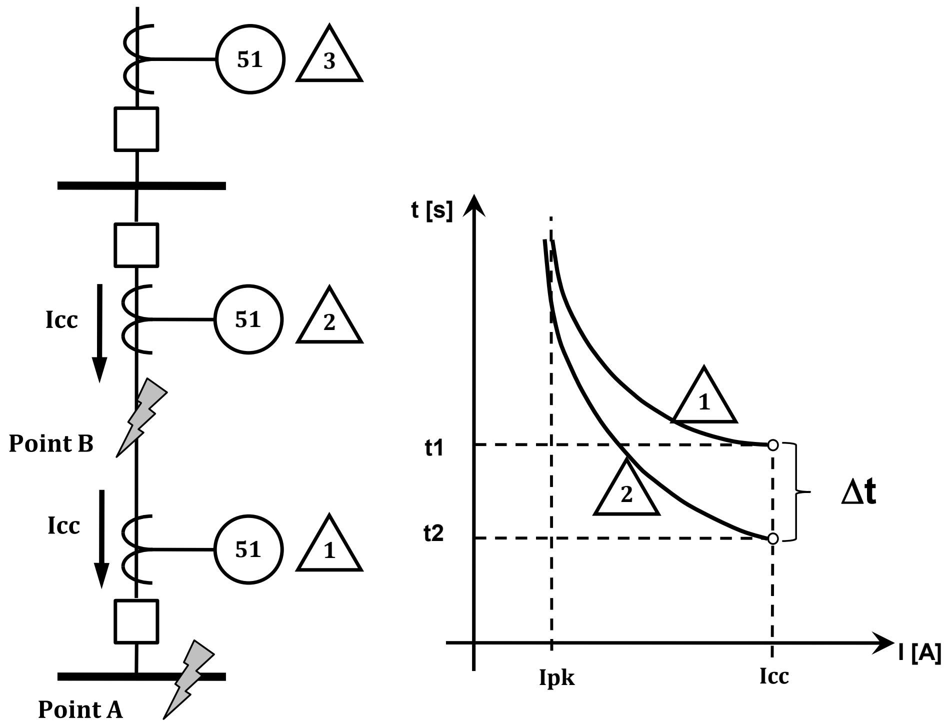
- Instantaneous elements "sees" Asymmetrical Momentary Current
- Delayed devices "sees" Asymmetrical or Symmetrical Current, depending on delay. Over 150 ms normally 30 cycles short-circuit current can be used instead.

Another important point is that differently from the case of equipment evaluation where we use the maximum short circuit current for protection coordination, we have to use the actual value of the short circuit current, otherwise, when a fault takes place, the actual value will be lower than the considered value and clearing time will be higher impacting and bigger damage and greater MTTR. For this reason, sometimes different scenarios and setting groups may be required.

CONCEPT OF HIGHER OUTGOING FEEDER SETTING - PROT DEVICES IN SERIES

EngePower® TREINAMENTOS

(a) Protective Devices in Series
Consider the oneline Diagram below. You received the TCC showed below and have to coordinate relay 3 with the downstream relay. The question is what relay shall you coordinate with 1 or 2?



Solution:
For the analysis, one shall look at the TCC, but also at the point of faults.

CONCEPT OF HIGHER OUTGOING FEEDER SETTING - PROT DEVICES IN SERIES

If the point of fault is A:
By the t x I curves (TCC), a fault applied at point A, relay 2 trips first.

If the point of fault is B:
By the t x I curves, a fault Applied at point B, Only the relay 2 “sees” and trips.

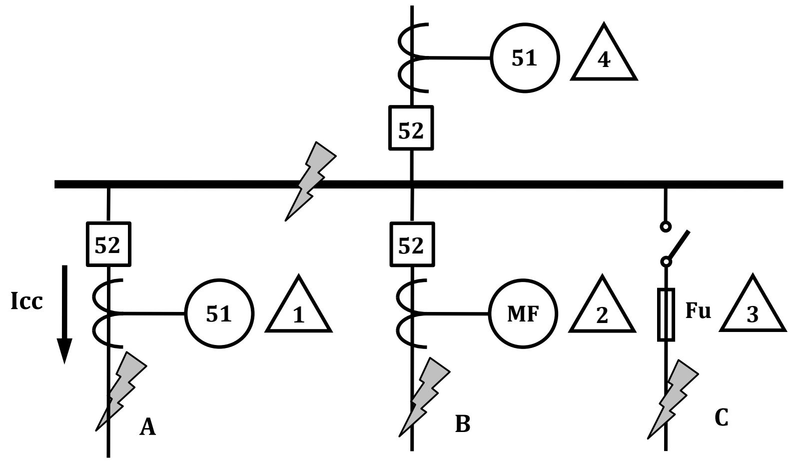
Conclusion:
Relay 3 must coordinate with relay 2. Even if there is a setting error in relay 1, for faults at any point, relay 2 always trips first. It is obvious that the setting error was made on purpose. If relay 1 was set below 2, for a fault at point A, relay 1 would trip first. For a fault at point B, relay 2 would trip, so relay 3, just as in the wrong case, must be selective with relay 2.

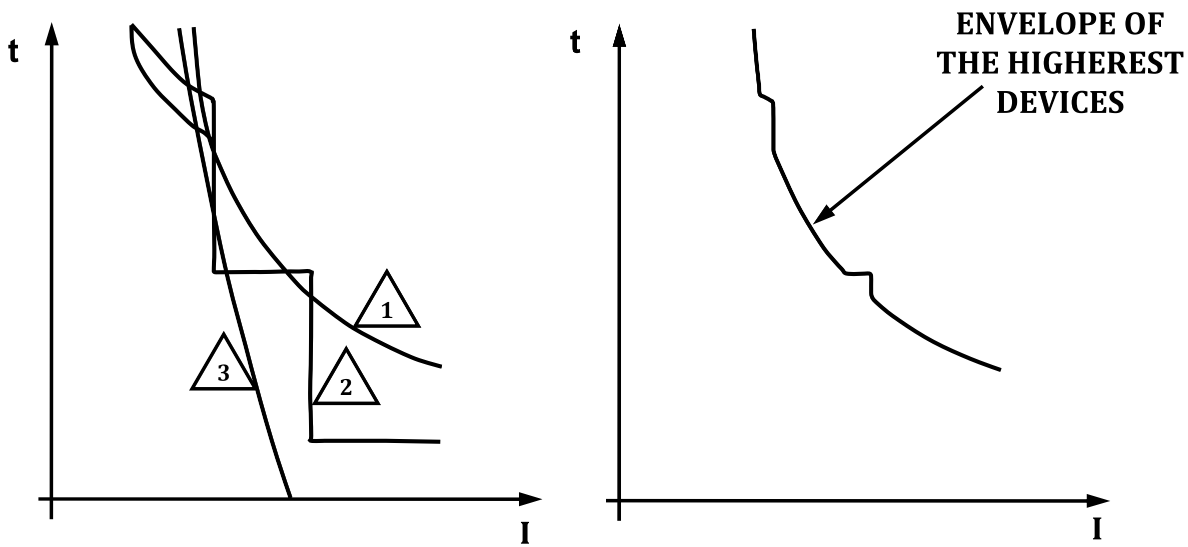
Moral of the Story:
When two protective devices are **in series**, coordination must be done with the one **immediately downstream, regardless of the settings**.

CONCEPT OF HIGHER OUTGOING FEEDER SETTING - PROT DEVICES IN PARALLEL

(b) Main Protective Device x Parallel Protective Devices in the Outgoing Feeders

<u>Rule</u>:
The main protective device shall **<u>shall coordinate with the downstream protective devices</u>** formed by the association of each outgoing feeder.





WHERE TO APPLY THE COORDINATION TIME INTERVAL ?

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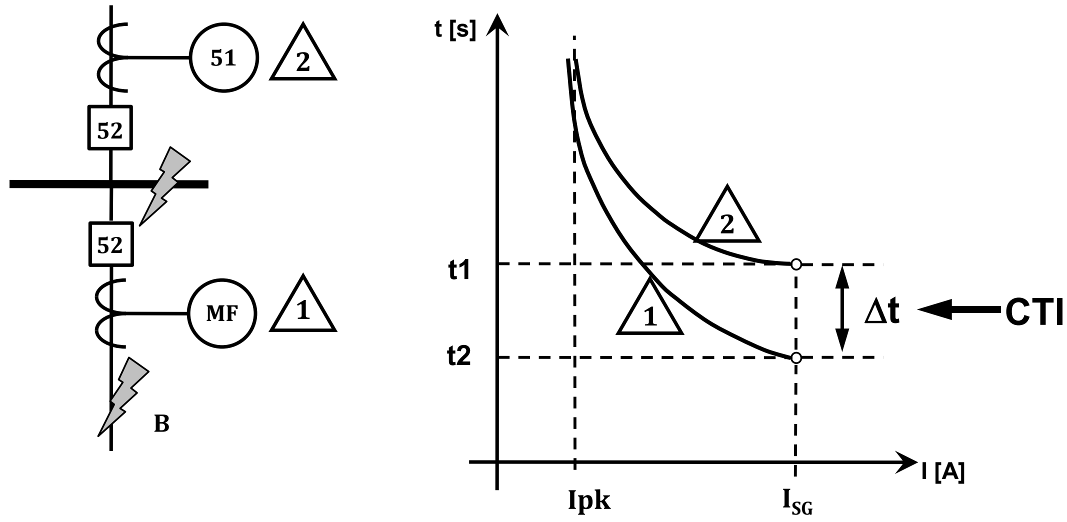
(a) RULE

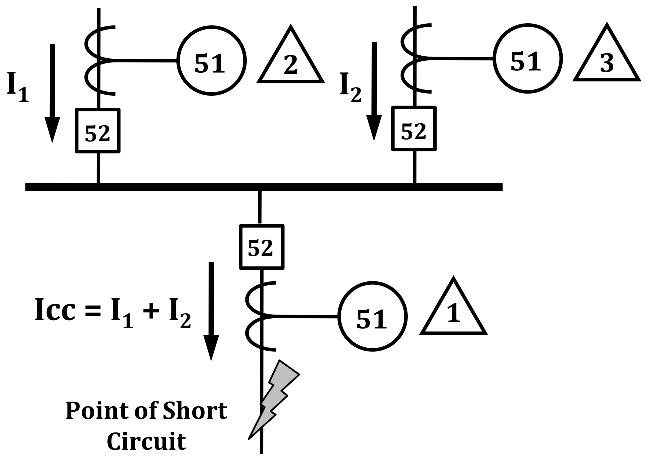
The coordination time interval shall be applied to the value of the bolted short-circuit current seen by the analyzed device, that is, three-phase short (transient/30 cycles) for phase coordination, and single line-to-ground short-circuit for ground coordination.

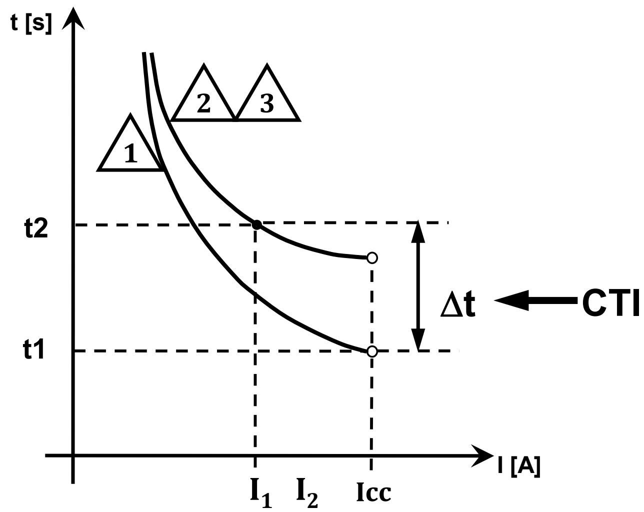


(b) SPECIAL CONDITIONS

(b1) Two Incoming Feeders + One Outgoing Feeder

Coordination time interval shall be applied at the short-circuit value seen by each protective device.





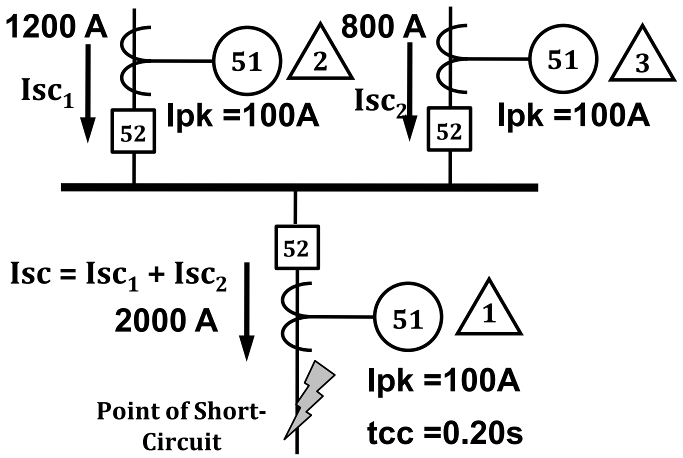
Note: If you want to set the same setting for the two upstream devices, you must coordinate with the one that "sees" the greater short current.

EngePower® TREINAMENTOS

(b) SPECIAL CONDITIONS

(b1) Two Incoming Feeders + One Outgoing Feeder

Coordination time interval shall be applied at the short-circuit value seen by each protective device.



Relé 1 - Curve – IEC VI

$$t = \frac{13.5}{M-1} \cdot DT \Rightarrow DT = t \cdot \frac{(M-1)}{13.5} \qquad M = \frac{Icc}{Ipk} = \frac{2000}{100} = 20$$

$$DT = 0.2 \cdot \frac{(20-1)}{13.5} = 0.28$$

Relé 2 - Curve – IEC - VI

$$t = \frac{13.5}{M-1} \cdot DT \Rightarrow DT = t \cdot \frac{(M-1)}{13.5} \qquad M = \frac{Icc}{Ipk} = \frac{1200}{100} = 12$$

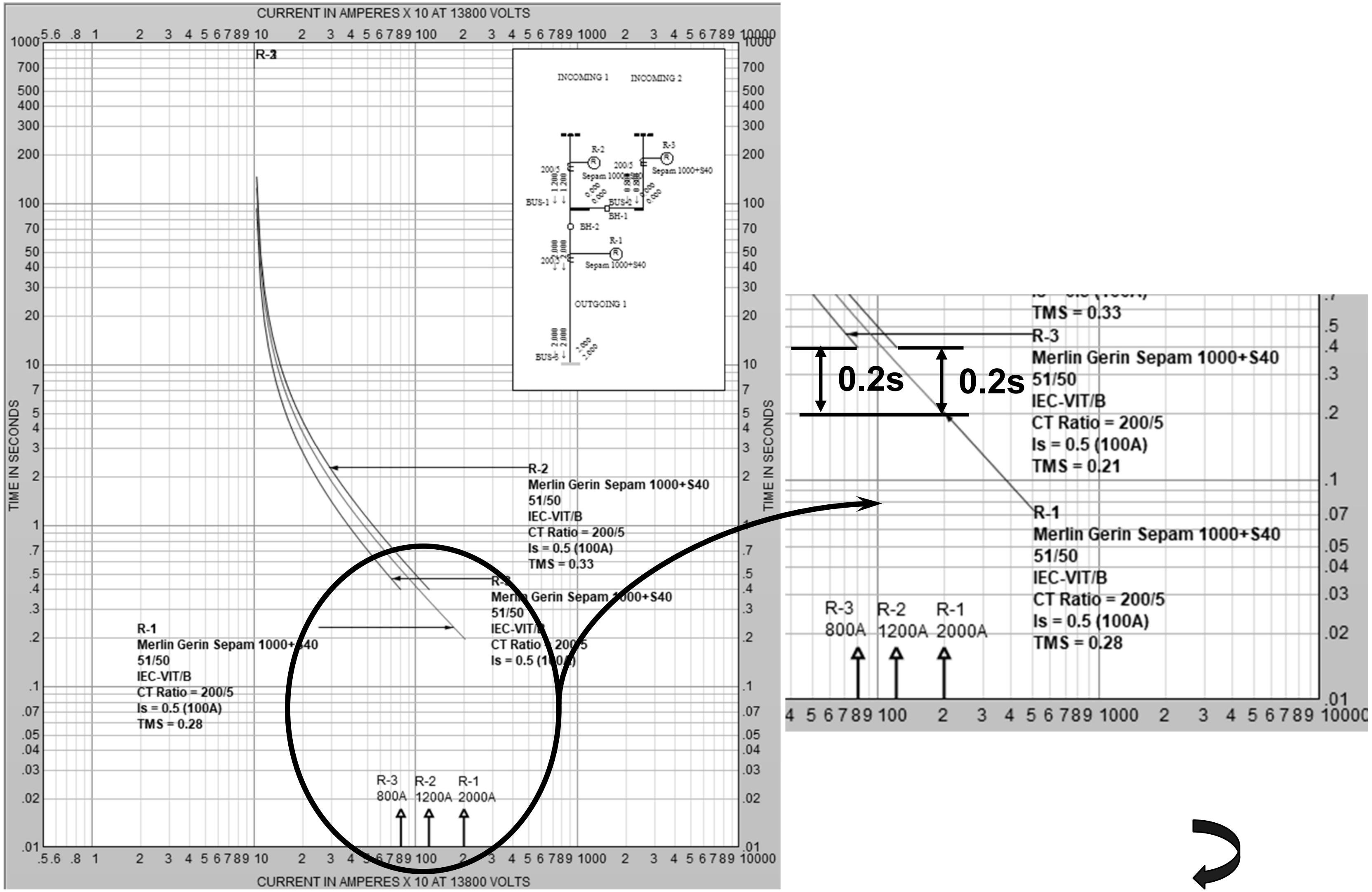
$$DT = 0.40 \cdot \frac{(12-1)}{13.5} = 0.33$$

Relé 3 - Curve – IEC VI

$$t = \frac{13.5}{M-1} \cdot DT \Rightarrow DT = t \cdot \frac{(M-1)}{13.5} \qquad M = \frac{Icc}{Ipk} = \frac{800}{100} = 8$$

$$DT = 0.40 \cdot \frac{(8-1)}{13.5} = 0.21$$

WHERE TO APPLY THE COORDINATION TIME INTERVAL ?



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WHERE TO APPLY THE COORDINATION TIME INTERVAL ?

(b2) Line-to-Line Short-Circuit at Secondary Side of Delta-Wye Transformer

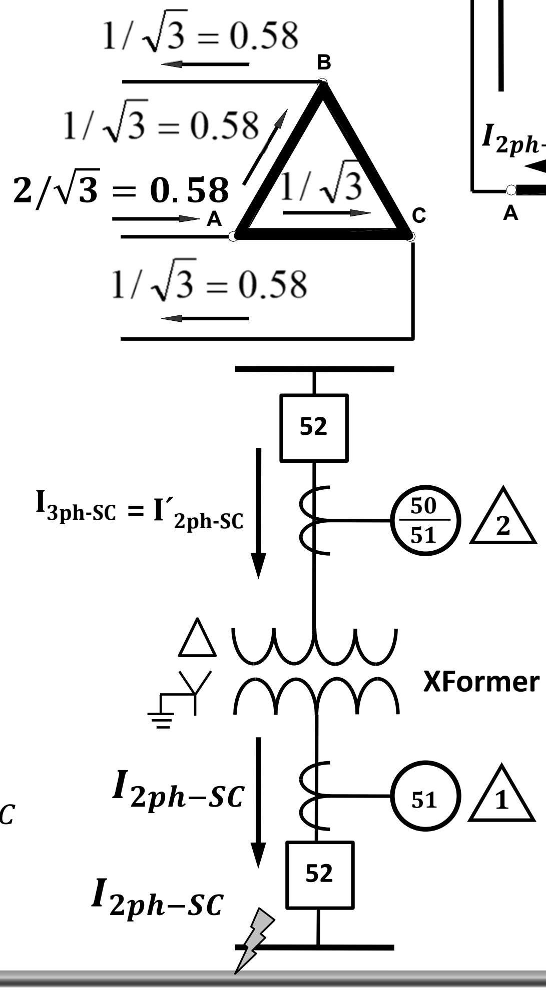
Coordination Time Interval shall be Applied between the short-circuit value Isc2ϕ (of the secondary protective device) and the 3-phase short-circuit value Isc3ϕ (seen by the primary side protective device).

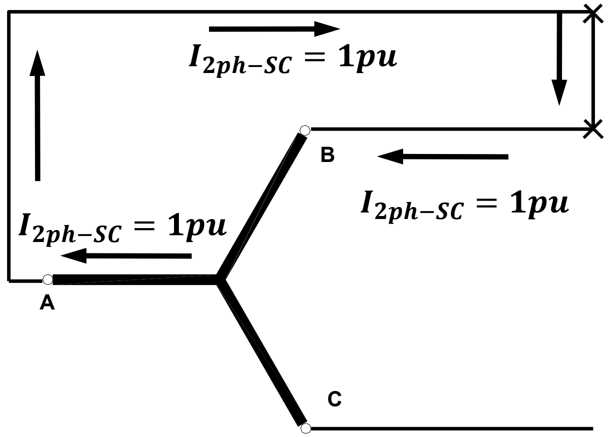
$$I_{2ph-HV-side} = \frac{2}{\sqrt{3}} \times I_{2ph-SC}$$

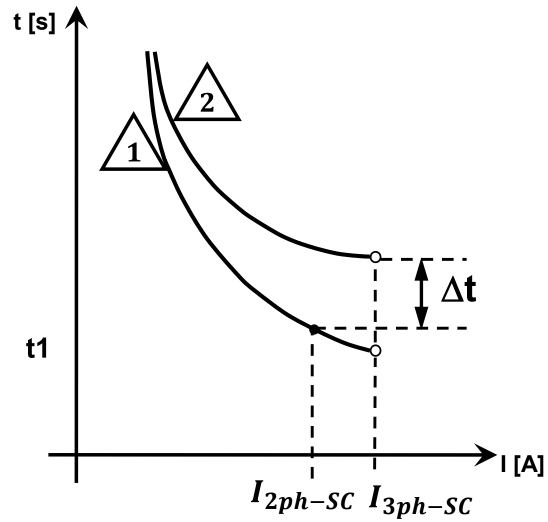
$$I_{2ph-SC} = \frac{\sqrt{3}}{2} \times I_{3ph-SC}$$

$$I_{2ph-HV-side} = \frac{2}{\sqrt{3}} \times \frac{\sqrt{3}}{2} \times I_{3ph-SC}$$

$$I_{2ph-HV-side} = I_{3ph-SC}$$







COORDINATION TIME INTERVAL

Coordination time interval is the time interval between two series protective devices that guarantees the one closest to the fault will operate first and the immediately upstream protective device will not operate, unless the closest one fails.

Before manufacturing of relay calibration set the CTI was 400 ms. With the advent of relay calibration set the new CTI changed to 300 ms as showed below, which guaranteed the relay operating time, the coordination time interval value could be lowered, as follows:

Coordination Between Two Series Overcurrent Relays	In the Old Days	In the Present Days
Breaker Interrupting Time (8 cycles)	133 ms	83 ms
Manufacturer Tolerance / Error/ Overtravel	100 ms	50 ms
Safety Margin Factor	67 ms	67 ms
Coordination Time Interval	300 ms	200 ms

When the static relays appeared, Overtravel was replaced by Overshoot and this time was reduced to 50 ms. Since 8-cycle circuit breakers are no longer used, a Coordination Interval of **200 ms** can be obtained. If **definite time elements** are used CTI can be reduced up to **150 ms**.

COORDINATION TIME INTERVAL (CTI)

According to Tables `15-2 and 15-3 fo the IEEE Std 242 the following CTI can be used:

Components	CTI with field testing	
	Electromechanical	Static
Circuit breaker opening time (5 cycles)	0.08 s	0.08 s
Relay overtravel	0.10 s	0.00 s
Relay tolerance and setting errors	0.12 s	0.12 s
Total CTI	0.30 s	0.20 s

Downstream	Upstream			
	Fuse	Low-voltage breaker	Electro-mechanical relay	Static relay
Fuse	CS[b,c]	CS	0.22 s	0.12 s
Low-voltage circuit breaker	CS[c]	CS	0.22 s	0.12 s
Electromechanical relay (5 cycles)	0.20 s	0.20 s	0.30 s	0.20 s
Static relay (5 cycles)	0.20 s	0.20 s	0.30 s	0.20 s

[a]Relay settings assumed to be field-tested and -calibrated.
[b]CS = Clear space between curves with upstream minimum-melting curve adjusted for pre-load.
[c]Some manufacturers may also recommend a safety factor. Consult manufacturers' time-current curves.

IMPORTANT:

Remember that **relays in the main** shall be set to a **maximum time of 1 second**, trying not to exceed this value, bearing in mind that all equipment is specified to withstand the short-circuit current for 1 second. That **1 second only protects equipment** but **does not provide personnel protection**.

COORDINATION TIME INTERVAL (CTI)

EngePower, my company uses the following CTI based on my 42 years of experience:

COORDINATION TIME INTERVAL				
Upstream Device	***Downstream Device***			
	Digital Relay/IED Note 5	***Electromechanical Relay/ Static***	***LV Breaker***	***Fuse***
Digital Relay/IED – Note 5	***0.20 s***	***0.30 s***	***0.15 s***	***0.20 s***
Electromechanical Relay/ Static	***0.30 s***	***0.30 s***	***0.20 s***	***0.20 s***
LV Breaker	***0.15 s***	***0.20 s***	***Note 1***	***Note 2***
Fuse	***0.20 s***	***0.20 s***	***Note 3***	***Note 4***

Notes:

1 – It is enough the bottom of the curve of the upstream breaker is above the downstream.

2 – It is enough the bottom of the breaker curve is above the max melting time curve.

3 - It is enough for the minimum melting time curve to be above the upper part of the circuit breaker curve.

4 - The I^2t of the downstream fuse must be lower than that of the upstream fuse.

5 – When coordination is done involving **directional elements**, **80 ms must be added** (element 67 takes more time to calculate the angle).

IMPORTANT:

Remember that **relays in the main** shall be set to a **maximum time of 1 second**, trying not to exceed this value, bearing in mind that all equipment is specified to withstand the short-circuit current for 1 second. That **1 second only protects equipment** but **does not provide personnel protection**.

COORDINATION TIME INTERVAL (CTI) FOR LOGICAL COORDINATION

CTI FOR LOGICAL COORDINATION

Between Devices that comunicate themselves:

Non-Directional Overcurrent Elements - **0.050 to 0.080 s**
Directional Overcurrent Elements - **0.100 to 0.120 s** (**Note 1**)

Note 1 = **Directional Elements** take more time to check directionality. Each IED of different manufacturer takes one time to perform this, and then, the ideal is to test this time on the bench, to have the correct time for each relay.
Typical time supplied by the manufacturer for the **67N** element shall consider:

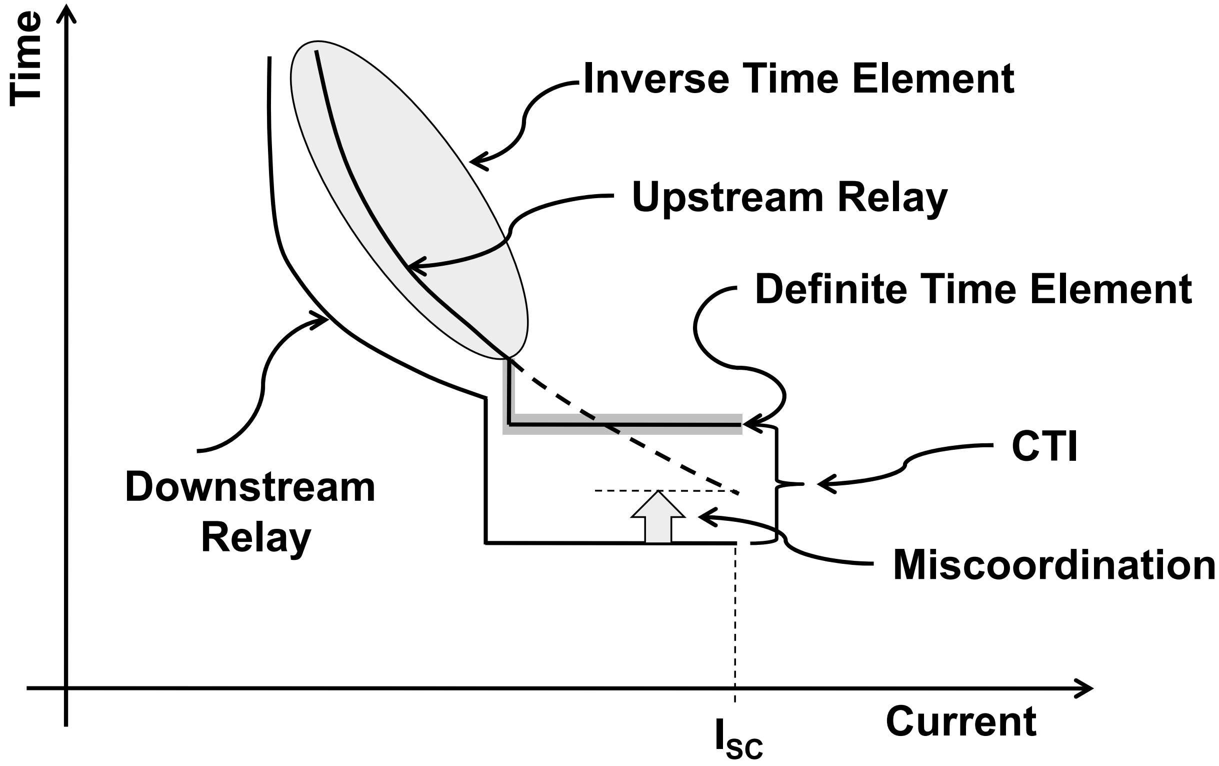
- Start time of the 67N element (reaction time
- Time for GOOSE transmission
- Possible delay due task of receiver IED
- Retardation time 67N element of the receiver IED
- Error Margin considering saturation

Note 2 – Locations where there are generators must be checked that the logic coordination time does not impact the limit of stability of the machines.

Between Devices that do not comunicate themselves in the logical coordination = tdd + ∆tc
Where : tdd - Time of the downstream device
∆tc – Coordination Time (**0.050s ou 0.100s** – Vide Note 1)

RELÉ DIGITAL COM VÁRIOS ELEMENTOS UTILIZADOS

(b3) Digital relay with two elements: one inverse time and other with delayed definite time.
When setting one inverse time element with another delayed definite time element in the same device, do not forget that the functions operate independently.



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(g) Line-to-Ground Arcing Current Estimation

Dunki-Jacobs did a fantastic job when he obtained the factor of 0.38 to estimate the line-to-ground arcing fault current value for protection purposes at 480V.

$I_{Arc\_Line\text{-}to\text{-}Ground}$ **= Factor (0.38) x Ibf** Where: Ibf = Bolted Fault Current

As there are no published literature on the subject in the IEEE, the arc current value can be estimated using the IEEE 1584-2018 equations, replacing the voltage and the distance between phases by the phase-to-ground. Let's see what the standard says in the item 4.11 on page 34:

4.11 Single-phase systems

This model does not cover single-phase systems. Arc-flash incident energy testing for single-phase systems has not been researched with enough detail to determine a method for estimating the incident energy. Single-phase systems can be analyzed by using the single-phase bolted fault current to determine the single-phase arcing current (using the equations provided in 4.4 and 4.10). The voltage of the single-phase system (line-to-line, line-to-ground, center tap voltage, etc.) can be used to determine the arcing current. The arcing current can then be used to find the protective device opening time and incident energy by using the three-phase equations provided in this guide. The incident energy result is expected to be conservative.

ESTIMATING THE SINGLE LINE-TO-GROUND ARCING FAULT CURRENT

Vide Planilha

Based on the assumption showed in the previous slide, the table containing the multiplying factors to be applied in bolted line-to-ground faults to obtain the single line-to-ground arcing current are presented below **for a gap of 32 mm**. This development was done the instructor of this webinar.

GAP = 32					
kVn	**kVA**	**Z%**	**HCB**	**VCB**	**VCBB**
0.22	500	5	0.2116	0.2326	0.2818
	750	5.5	0.1947	0.2089	0.2578
	1000	5.75	0.1735	0.1827	0.2260
	1500	6	0.1337	0.1384	0.1694
	2000	6	0.3130	0.3230	0.3833
	2500	6			
	3000	6			
Mínimo			**0.1337**	**0.1384**	**0.1694**
0.38	500	5	0.3538	0.3948	0.4407
	750	5.5	0.3553	0.3915	0.4531
	1000	5.75	0.3468	0.3772	0.4456
	1500	6	0.3154	0.3347	0.4047
	2000	6	0.2733	0.2849	0.3466
	2500	6	0.2337	0.2416	0.2935
	3000	6	0.2010	0.2076	0.2511
Mínimo			**0.2010**	**0.2076**	**0.2511**

GAP = 32					
kVn	**kVA**	**Z%**	**HCB**	**VCB**	**VCBB**
0.48	500	5	0.4273	0.4720	0.5210
	750	5.5	0.4307	0.4740	0.5312
	1000	5.75	0.4287	0.4681	0.5335
	1500	6	0.4105	0.4400	0.5157
	2000	6	**0.3774**	0.3975	0.4741
	2500	6	0.3386	0.3524	0.4235
	3000	6	0.3011	0.3750	0.3112
Mínimo			**0.3011**	**0.3524**	**0.3112**
0.69	500	5	0.5433	0.5869	0.6315
	750	5.5	0.5495	0.5949	0.6422
	1000	5.75	0.5531	0.5980	0.6501
	1500	6	0.5518	0.5921	0.6551
	2000	6	0.5391	0.5725	0.6451
	2500	6	0.5175	0.5443	0.6227
	3000	6	0.4903	0.5115	0.5920
Mínimo			**0.4903**	**0.5115**	**0.5920**

Thus, currently, for protection purposes, the yellow highlighted factors represent the minimum value, and they can be used as a good practice:
(a) for **220 V**, the factor of **0.13**, (b) for **380 V**, the factor of **0.20,**
(c) for **480 V**, the factor of **0.30** and for **690 V**, the factor of **0.49**.

EngePower® TREINAMENTOS

ESTIMATING THE SINGLE LINE-TO-GROUND ARCING FAULT CURRENT

Vide Planilha

Based on the assumption showed in the previous slide, the table containing the multiplying factors to be applied in bolted line-to-ground faults to obtain the single line-to-ground arcing current are presented below **for a gap of 25 mm**. This development was done the instructor of this webinar.

GAP = 25					
kVn	**kVA**	**Z%**	**HCB**	**VCB**	**VCBB**
0.22	500	5	0.2262	0.2457	0.2942
	750	5.5	0.2069	0.2191	0.2677
	1000	5.75	0.1830	0.1904	0.2333
	1500	6	0.1395	0.1430	0.1734
	2000	6	0.1078	0.1110	0.1326
	2500	6			
	3000	6			
Mínimo			**0.1098**		
0.38	500	5	0.3788	0.4173	0.4648
	750	5.5	0.3773	0.4113	0.4695
	1000	5.75	0.3678	0.3954	0.4613
	1500	6	0.3326	0.3488	0.4173
	2000	6	0.2863	0.2952	0.3557
	2500	6	0.2435	0.2492	0.3000
	3000	6	0.2087	0.2135	0.2560
Mínimo			**0.2087**		

GAP = 25					
kVn	**kVA**	**Z%**	**HCB**	**VCB**	**VCBB**
0.48	500	5	0.4511	0.4933	0.5366
	750	5.5	0.4548	0.4922	0.5474
	1000	5.75	0.4526	0.4890	0.5499
	1500	6	0.4324	0.4583	0.5309
	2000	6	**0.3955**	0.4121	0.4863
	2500	6	0.3538	0.3643	0.4336
	3000	6	0.3135	0.3209	0.3830
Mínimo			**0.3135**		
0.69	500	5	0.5664	0.6064	0.6447
	750	5.5	0.5730	0.6149	0.6558
	1000	5.75	0.5769	0.6181	0.6640
	1500	6	0.5755	0.6119	0.6692
	2000	6	0.5618	0.5911	0.6589
	2500	6	0.5388	0.5614	0.6355
	3000	6	0.5098	0.5269	0.6038
Mínimo			**0.5098**		

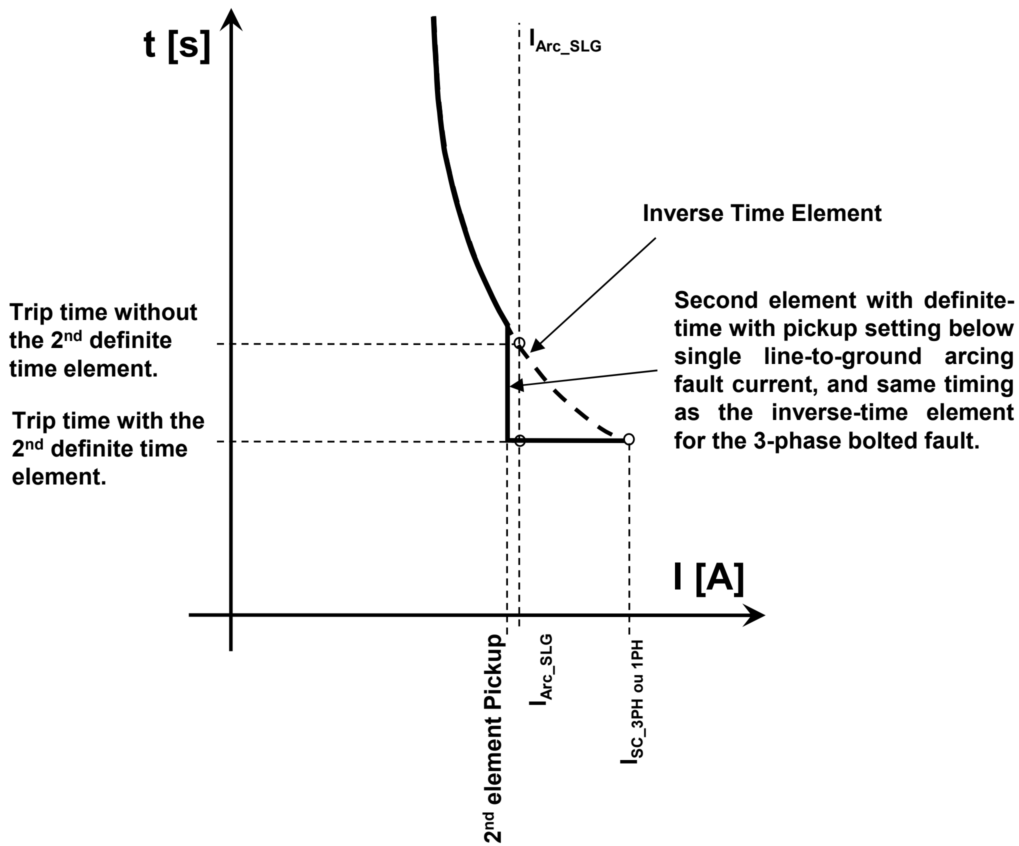
Thus, currently, for protection purposes, the yellow highlighted factors represent the minimum value, and they can be used as a good practice:
(a) for **220 V**, the factor of **0.11**, (b) for **380 V**, the factor of **0.20,**
(c) for **480 V**, the factor of **0.31** and for **690 V**, the factor of **0.50**.

Summary $I_{Arc\text{-}SLG}$

Voltage	Factor I_Arc_SLG
220 V	0.11
380 V	0.20
480 V	0.30
690 V	0.49

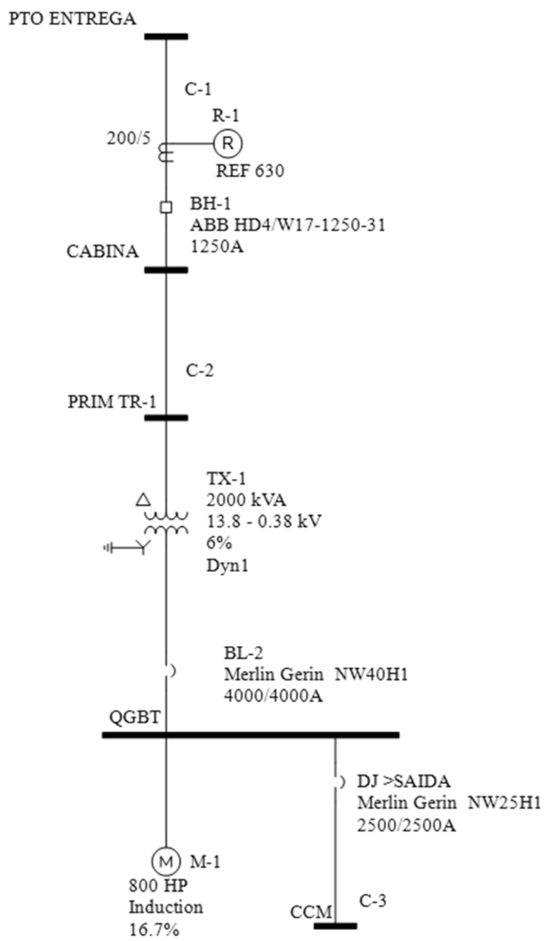
SINGLE LINE-TO-GROUND ARCING FAULT CURRENT

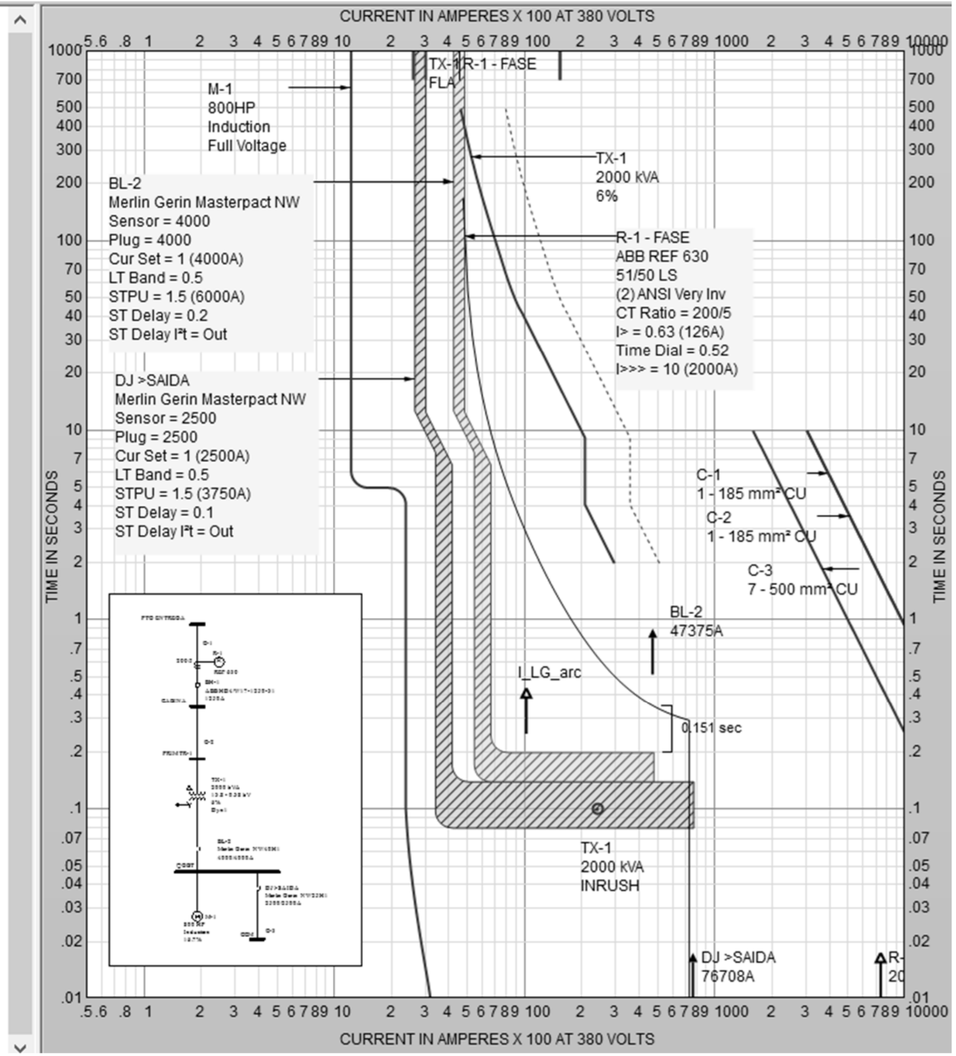
The objective of knowing this factor is to allow a setting of second definite-time element to be enabled, however, set to a pickup value below the single line-to-ground arcing fault current, in order to provide a fault clearing time equal to the same time of a 3-phase bolted fault current.



O/C COORDINATION JUST IN TIME OF AF STUDY

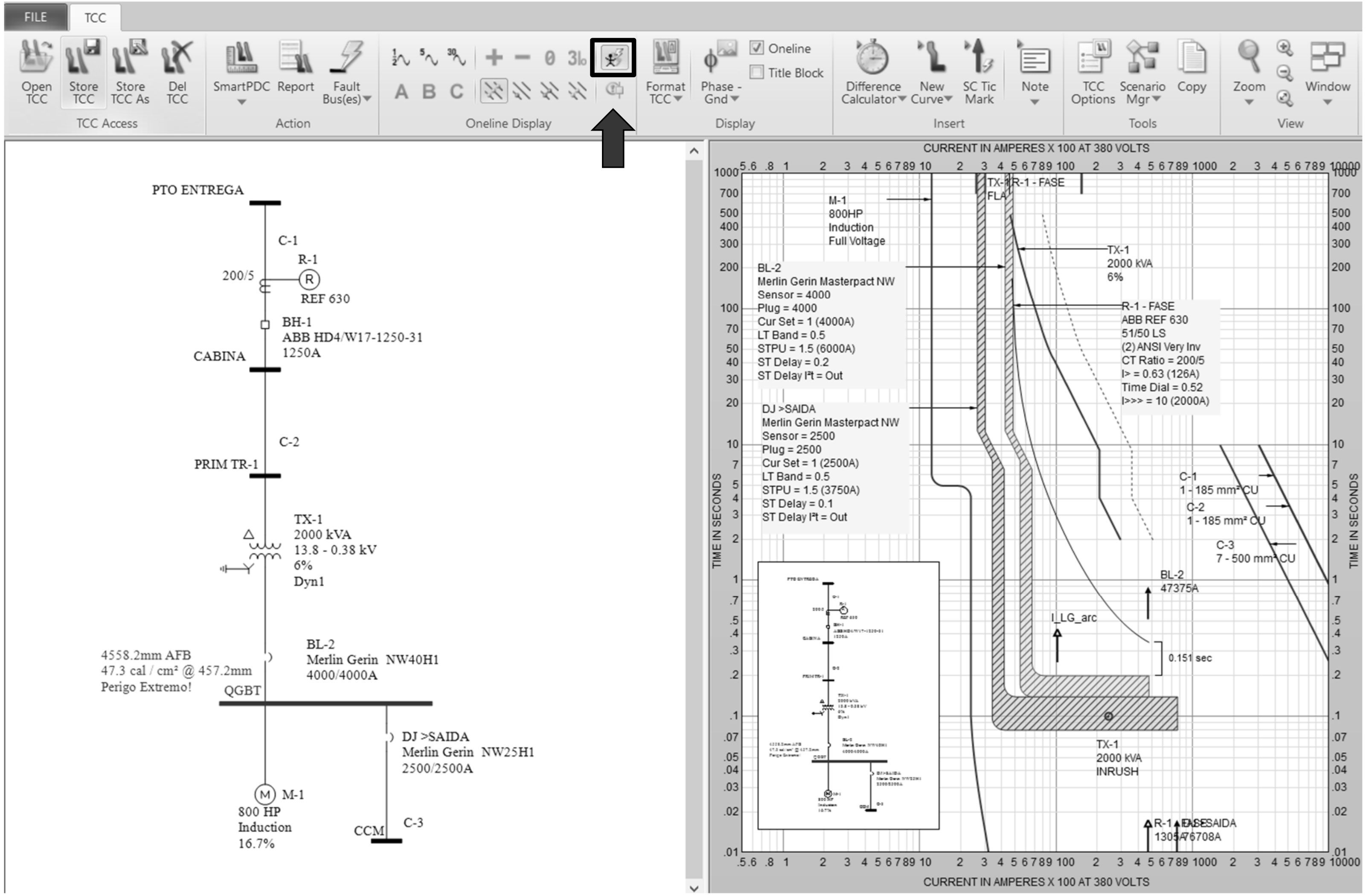
Consider you have a system with the oneline diagram and its correspondent TCC showed below:





O/C COORDINATION JUST IN TIME OF AF STUDY

Consider you have a system with the oneline diagram and its correspondent TCC showed below:



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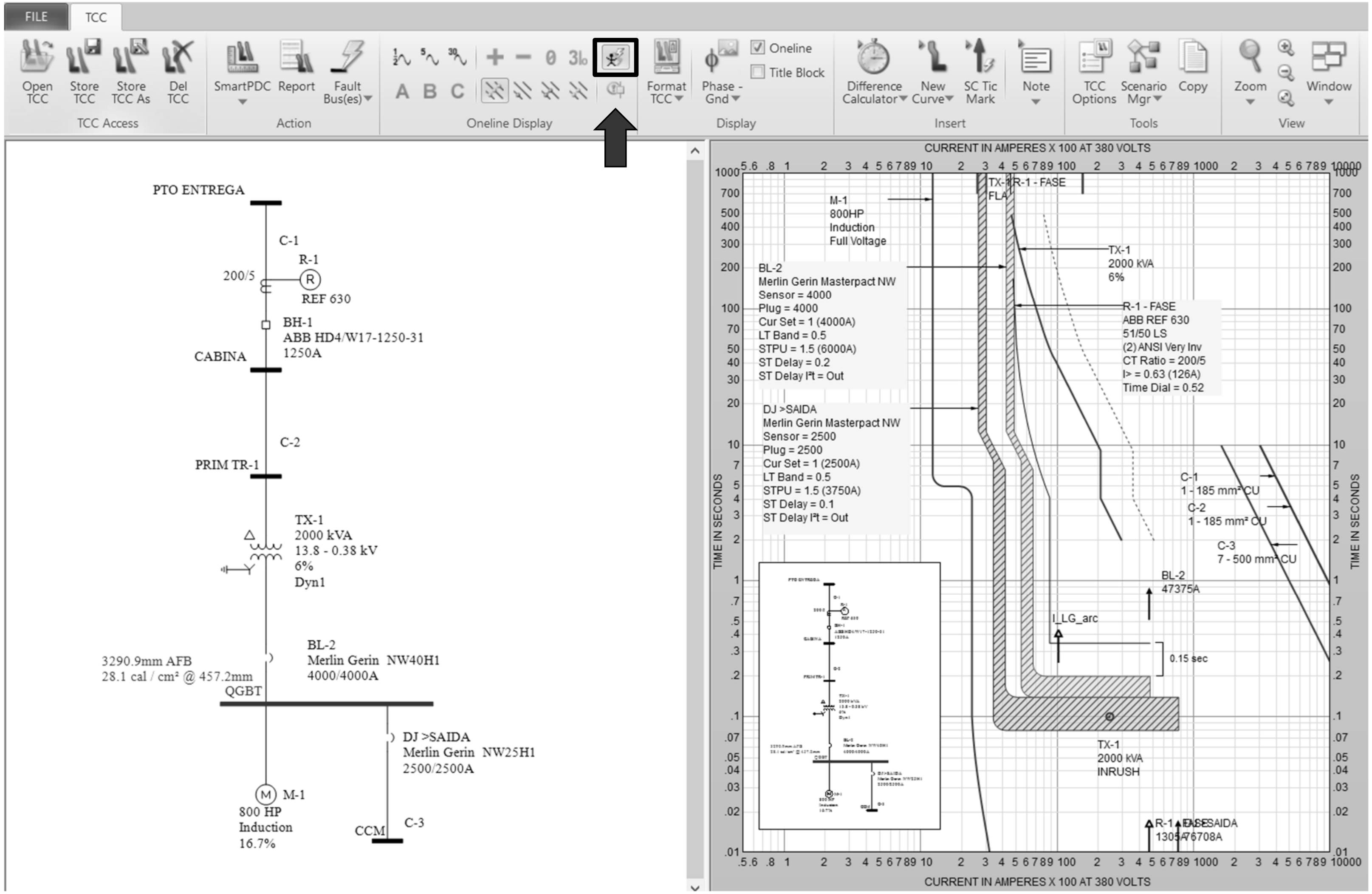
O/C COORDINATION JUST IN TIME OF AF STUDY

Consider you have a system with the oneline diagram and its correspondent TCC showed below:



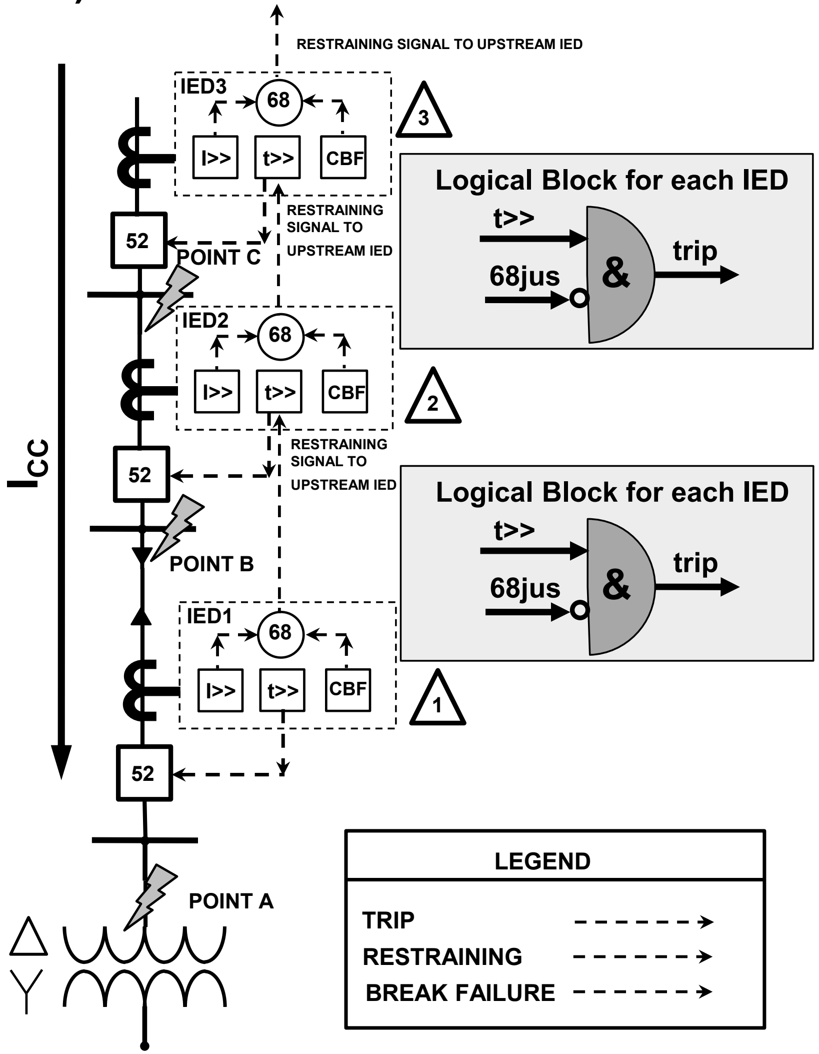
LOGICAL COORDINATION

In this topic will be discussed :

a) Principle of logical coordination
b) What are the advantages of using it?
c) Applicability of Logic Coordination for Phase and Ground Protection
d) Applicability regarding the voltage level
e) Determining the pick-up of the IEDs involved in the Logic Coordination
f) Restraining signals addressing
g) TCC plot showing Conventional Coordination and Logical Coordination

LOGICAL COORDINATION

a) PRINCIPLE OF LOGICAL COORDINATION



Logic Coordination is applied through digital relays that allow the units located closest to the fault **to clear** the fault in a **very short ti**me, normally between **50 and 120 ms**. Protection devices must be able to **discretize the pick-up from the time**, in addition to have **breaker failure feature**. The presented figure illustrates the philosophy.

In some cases, it is not possible to use time delays between 50 to 100 ms, since there may be fuses downstream and therefore, they must be allowed to operate before, and the total time for extinguishing the arc may reach 200 ms, therefore, when this occurs, the delay setting of the overcurrent element shall be between 200 and 250 ms. In this case, the timing (t>>) of the upstream relays will be 100 ms.

CBF timing is normally in the range 100 ~200ms. See examples.

LOGICAL COORDINATION

b) What are the advantages of using it?

The main advantages of logical coordination are:

- Decrease the time of conventional coordination
- Decrease the value of incident energy
- Ensure that just the protective device closest to the fault trips
- Have the second-level elements as a backup when the first-level elements fail
- Having conventional coordination as a backup of logical coordination
- The short circuit immediately below each IED will always clear the fault within the time defined in the logic coordination (normally < 100 ms)
- In systems with generators, the use of logic coordination reduces the protection clearing time during short-circuit and consequently improves the recovery of the stability of the synchronous machines in the system.

LOGICAL COORDINATION

c) Applicability of Logic Coordination for Phase and Ground Protection

Logic coordination can be applied for both phase and ground elements.

Ground logic coordination is not performed in locations where the system is grounded by high resistance grounding (HRG). The reason is that, as the value of the fault current is very low, it is not necessary to trip the first ground fault and thus, the loads continue to be supplied.

d) Applicability regarding the voltage level

The logic coordination shall be done for each voltage level, never from one level to the other.

The reason is that the transformer impedance will impose a lower current value on the secondary side and thus, it is possible to discretize when a short-circuit value is at one voltage level and another. Incidentally, this is one of the criteria for determining the pick-up of overcurrent elements involved in logic coordination..

LOGICAL COORDINATION

e) Determining the pick-up of the IEDs involved in the Logic Coordination

The determination of the pick-up of the IEDs involved in the Logical Coordination shall consider at least the following criteria:

Phase Elements

e1) The pick-up of the phase elements must be greater than the maximum asymmetrical secondary short-circuit current, but with as many sources as possible.

e2) The pick-up of the phase elements must be greater than the transformer inrush current.

e3) The pick-up of the phase elements must be greater than the power panel load current plus the largest motor starting.

e4) The pick-up of the phase elements must be greater than the contribution current of the motors.

e) Determining the pick-up of the IEDs involved in the Logic Coordination

The determination of the pick-up of the IEDs involved in the Logical Coordination shall consider at least the following criteria:

Ground Elements

e1) The pick-up of the ground elements must be greater than the maximum asymmetrical secondary short-circuit current when the connection allows zero sequence passing (YY grounded on both sides), but with as many sources as possible.

e2) The pick-up of the ground elements must be greater than CTs errors for the transformer inrush current.

e3) The pick-up of the ground elements shall be greater than the motors short-circuit current contribution.

LOGICAL COORDINATION

f) Restraining Signal Addressing

The restraining signals addressing can be done directly on the single-line diagram and/or in tabular form (table). See the examples.

Column 1: Identification of the relay / cubicle that sends the restraining signal;

Column 2: Protection function that sends the restraining signal;

Column 3: Identification of the relay/cubicle that receives the restraining signal;

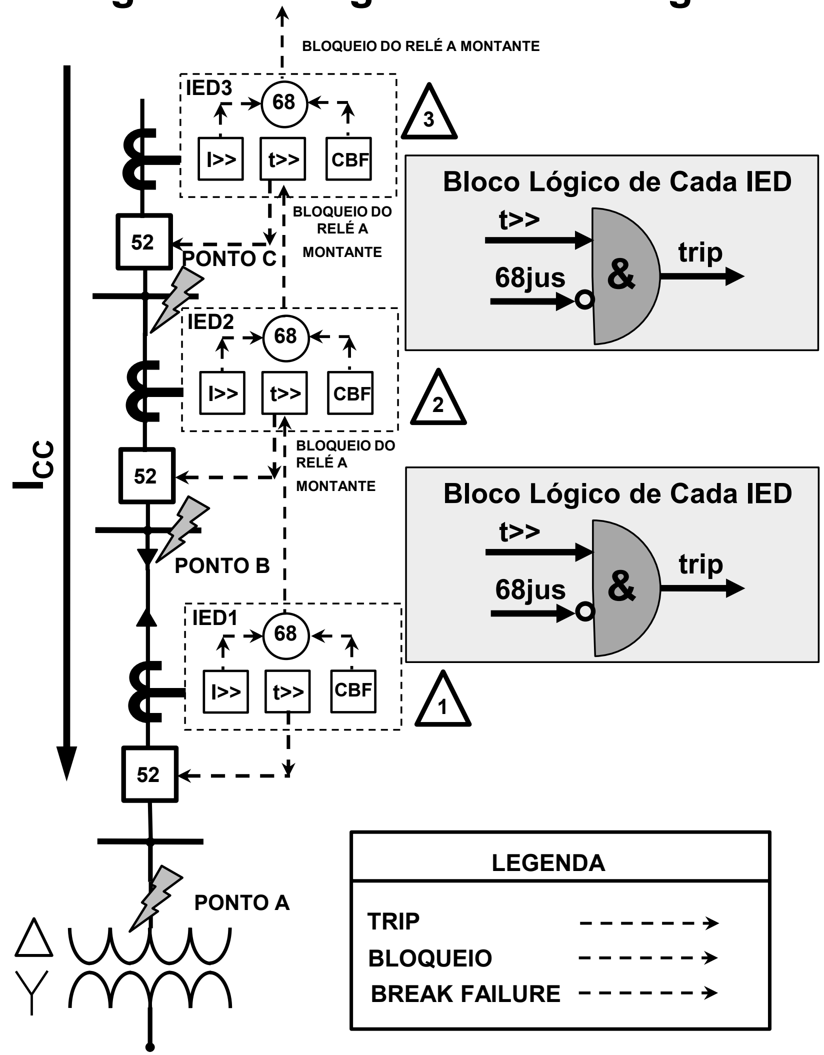
Column 4: Logic input /Protection function that receives restraining signal;

37400-A-01A SWGR – 34.5 kV			
1	2	3	4
IED Ident (Signal Sending)	SENT SIGNAL	SEND SIGNAL TO (Signal Receiving)	SEND RECEIVED (In the Logical Input)
CUBICLES C01/C04/C05/C06/C07/C08/C09/C10/ C11/C12/C13/C14/C15/C16/C17 REF630	START PHIPTOC1: 1 (3I>>>[1])	CUBÍCULOS: C18 (RET630) - C19A/C19B (REF630) PAINEL 37400-A-01A	BLK_OPR PHIPTOC1: 1 (3I>>> [1])
	START EFIPTOC1: 1 (I0>>>[1])		BLK_OPR EFIPTOC1: 1 (I0>>>[1])
	TRBU CCBRBRF(3I>/I0>BF; 51BF/51NFB):1		TRIP EXTERNO
	START PHIPTOC1: 1 (3I>>>[1])	CUBÍCULOS C01A/C01B (REF630) PAINEL 37400-A-01B	BLK_OPR DPHHPDOC: 1 (3I>>->[1])
	START EFIPTOC1: 1 (I0>>>[1])		BLK_OPR DEFLPDEF: 1 (I0>->[1])
	TRBU CCBRBRF(3I>/I0>BF; 51BF/51NFB):1		TRIP EXTERNO
	START PHIPTOC1: 1 (3I>>>[1])	CUBÍCULOS C1A/C1B (REX640) PAINEL 37400-A-01C	BLK_OPR DPHHPDOC: 1 (3I>>->[1])
	START EFIPTOC1: 1 (I0>>>[1])		BLK_OPR DEFHPDEF: 1 (I0>>->[1])
	TRBU CCBRBRF(3I>/I0>BF; 51BF/51NFB):1		TRIP EXTERNO
	START EFIPTOC1: 1 (I0>>>[1])	CUBÍCULO C02 PAINEL 37400-A-01A REF630	BLK_OPR EFIPTOC1: 1 (I0>>>[1])
	TRBU CCBRBRF(I0>BF; 51NFB):1		TRIP EXTERNO

Single Line-Diagram Addressing

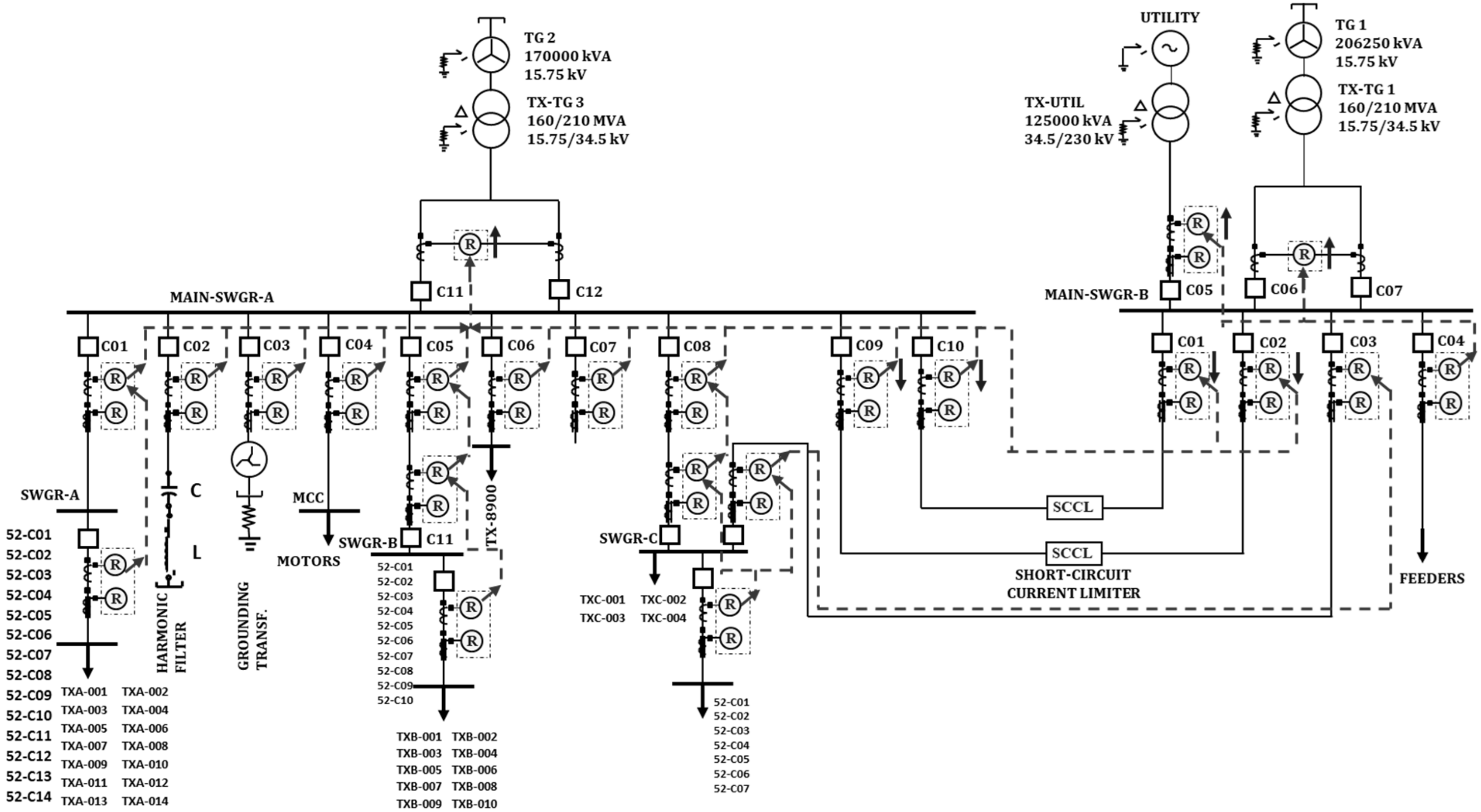
f) Restraining Signal Addressing

The restraining signals addressing can be done directly on the single-line diagram and/or in tabular form (table). See the examples.



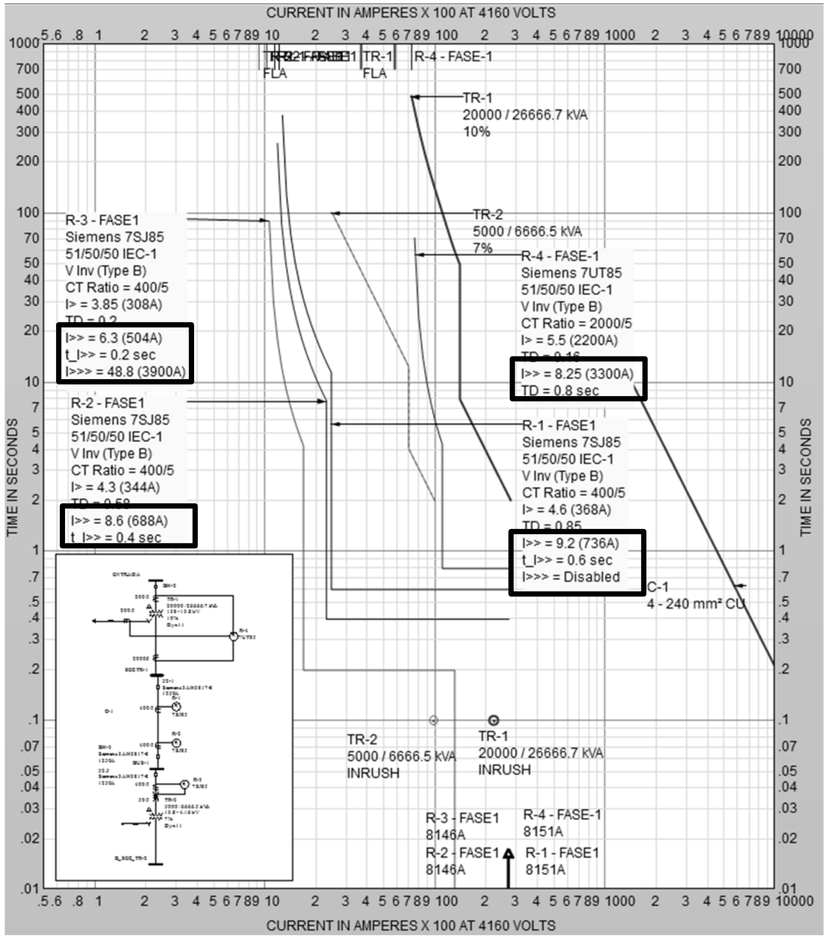
f) Restraining Signal Addressing

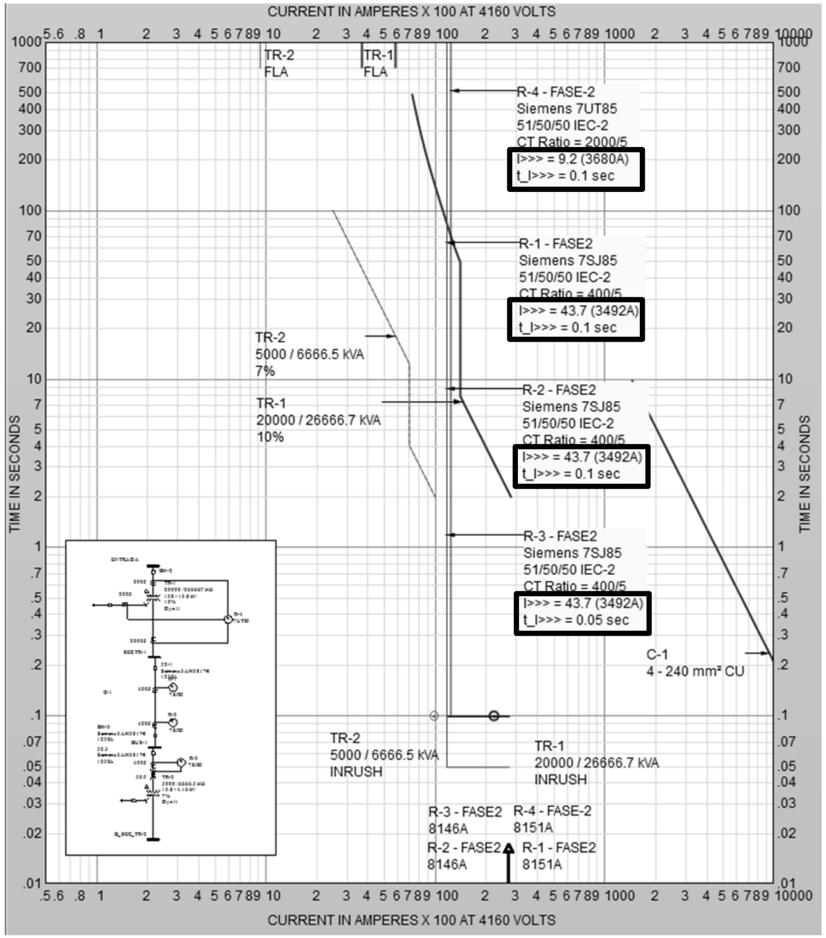
Single Line-Diagram Addressing



LOGICAL COORDINATION

g) TCC plot showing Conventional Coordination and Logical Coordination





THE END OF

PART TWO!

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QUESTIONS ?

THANK YOU VERY MUCH!

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