The Use of Software for Electrical Fault Current Calculations

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Why use Software ?

In all applications, the electrical fault current can be easily calculated by assuming a source with infinite fault capacity, ignoring cable impedance and considering only the impedance of the transformers. However such quick method will produce conservative values of fault current and will result in the need to use circuit breakers with ratings that are well in excess of the actual electrical fault current. The use of software will provide a more accurate and realistic value of the actual fault current.

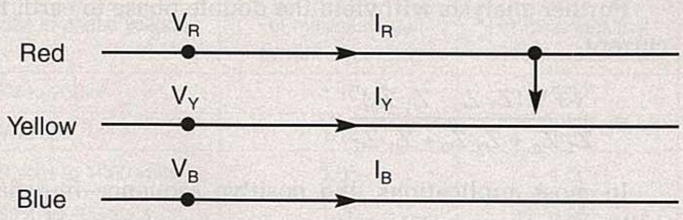
This article will share my experience in the use of ETAP software from USA. Once the network is modelled, the software will calculate values for 3 phase fault, single phase to earth fault, double phase to earth fault, phase to phase fault, voltage magnitude at the faulted phase, and voltage magnitude at the healthy phase.

The electrical fault current must be calculated at each and every level in the electrical installation. The maximum and minimum fault current must be calculated, and each will be used for different purpose. The maximum fault current is used to determine the breaking and making rating of the circuit breakers. The minimum fault current is used for protection relay co-ordination.

Symmetrical Components

The ETAP software uses the method of symmetrical components to determine the current and voltage in all parts of the system after the occurrence of the fault. There are many excellent material on the method of symmetrical components and how to derive the various equations for phase to phase fault, single phase to earth fault and double phase to earth fault. The reader is encouraged to review such material, and this article will be more on the application of the various equations [1]. In the original form, these equations are difficult to use and remember. It will be more useful to express these equations as a function of the three phase fault.

Single Phase to Earth Fault



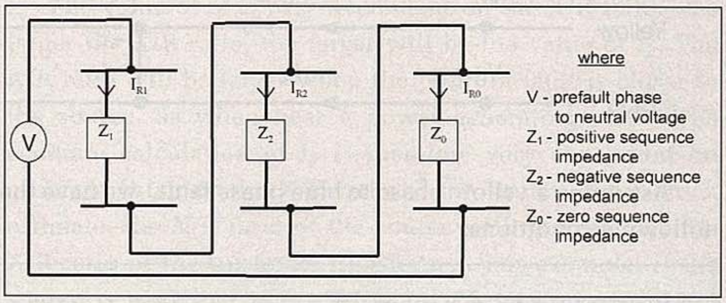
Assuming a red phase to earth fault, we have the following conditions;

$$I_R = I_{R1} + I_{R2} + I_{R0} \quad \text{(red phase to earth fault current)}$$
$$I_Y = I_B = 0, \quad V_R = 0$$

where

- I_{R1} - Red phase positive sequence impedance current
- I_{R2} - Red phase negative sequence impedance current
- I_{R0} - Red phase zero sequence impedance current

The analysis of the conditions will lead to the impedance diagram for the red phase;



From the impedance diagram, we have the following

$$I_{R1} = I_{R2} = I_{R0},$$
$$V = I_{R1} Z_1 + I_{R2} Z_2 + I_{R0} Z_0$$

Further analysis will yield the single phase to earth fault

$$= \frac{3V}{Z_1 + Z_2 + Z_0}$$

In most applications, the positive sequence impedance is the same as the negative sequence Impedance. The single phase to earth fault current will reduce to

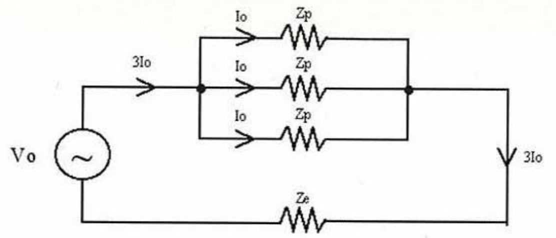
$$\left(\frac{3}{2 + Z_0/Z_1}\right) \times \text{three phase fault}$$

The ratio of (Z_0/Z_1) will rarely be close to unity, and often much greater than unity.

In most cases, the magnitude of the single phase to earth fault will be smaller than the three phase fault. This is because of the involvement of the cable impedance in the fault impedance. The zero sequence impedance of a cable will be much greater than the positive sequence impedance of the same cable. Hence the ratio of the system (Z_0/Z_1) at the point of fault will be much greater than 1. This will cause the single phase to each fault to be always less than the three phase fault.

In a typical 400 volts installation with TNS earthing, the common practice is to install separate earth cable and lay next to the phase cable. Figure 1 shows the derivation of the zero sequence impedance of a cable with separate earth cable.

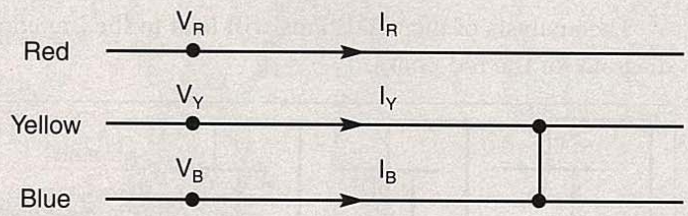
Figure 1



$V_o = I_oZ_p + 3I_oZ_e$
$(V_o/I_o) = Z_o = Z_p + 3Z_e$

Where **Zp** is the impedance of the Red, Yellow and Blue phase conductor.
Ze is the impedance of the separate earth cable.
Zo is the zero sequence impedance of the cable with separate earth cable.
Vo is the single phase source.

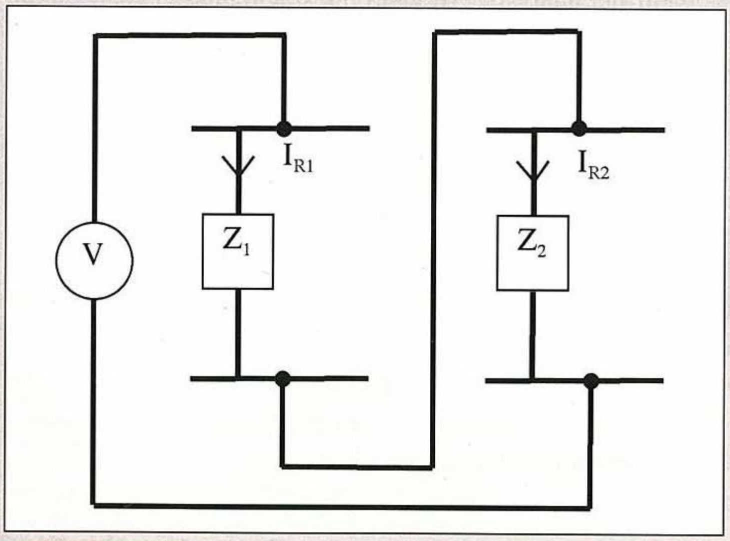
Phase to Phase Fault



Assuming a yellow phase to blue phase fault, we have the following conditions;

$I_R = I_{R1} + I_{R2} + I_{R0} = 0$
$I_B = I_Y, \; V_B = V_Y$

The analysis of the conditions will lead to the impedance diagram for the red phase;



From the impedance diagram, we have the following
$I_{R1} = I_{R2}$,
$V = I_{R1} Z_1 + I_{R2} Z_2$

Further analysis will yield the phase to phase fault current

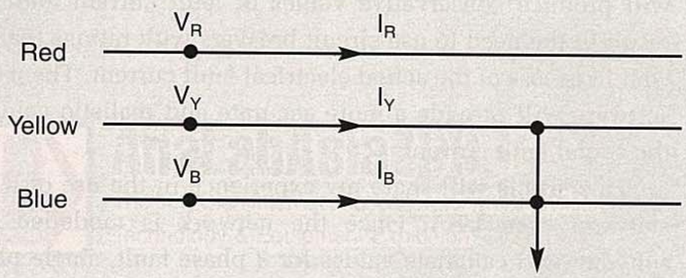
$$= \frac{\sqrt{3}\, V}{Z_1 + Z_2}$$

In most applications, the positive sequence impedance will be the same as the negative sequence impedance. The ratio of (Z_2/Z_1) will be close to unity.

The equation is reduced to ;

Phase to phase fault current $= \frac{\sqrt{3}}{2}$ x three phase fault
$= 86\%$ x three phase fault

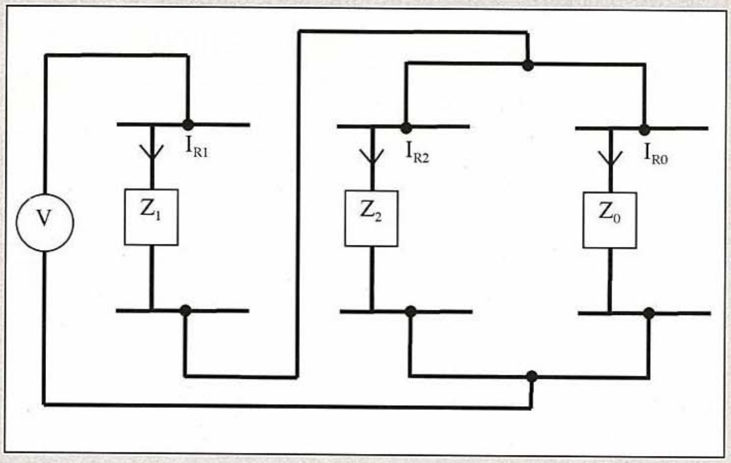
Double Phase to Earth Fault



Assuming a yellow phase and blue phase fault to earth; we have the following conditions;

$I_R = I_{R1} + I_{R2} + I_{R0} = 0$
$V_Y = V_B = 0$

The anlaysis of the conditions will lead to the impedance diagram for the red phase;



From the impedance diagram, we have the following
$I_{R1} = I_{R2} + I_{R0}$,
$I_{R2} Z_2 = I_{R0} Z_0$

Further analysis will yield the double phase to earth fault current

$$= \frac{\sqrt{3}\, V\,(Z_1 Z_2 - Z_1 Z_0)}{Z_1 Z_0 + Z_2 Z_0 + Z_1 Z_2}$$

In most applications, the positive sequence impedance will be the same as the negative sequence impedance.

The equation is reduced to ;

$$\text{Double phase to earth fault} = \frac{\sqrt{3}\,(Z_1 - Z_0)}{Z_1 + 2Z_0} \times \text{three phase fault}$$

IEC 909

The IEC 909 is the dominant standard for calculation of fault current. The purchase of any software for fault current calculation must require the software to comply with the IEC 909. IEC 909 classify the fault current according to their magnitude (maximum or minimum) and fault distance from the source (far or near). The maximum fault current will determine the equipment ratings, while minimum fault current will determine the settings of protection devices. Far from source and near to source classification will determine whether to include the decay of the AC component of the fault current.

In IEC 909, an equivalent voltage source at the fault location will replace all voltage sources. A voltage factor will adjust the value of the equivalent voltage source for the maximum and minimum fault current calculations. All transformers, generators, motors and cables are represented by their respective positive, negative and zero sequence impedance.

IEC 909 has many parameters which will describe the fault current at the sub-transient time, transient time and steady state time. A brief overview of the more important parameters will be essential.

I_K" - Initial Symmetrical Short Circuit Current

It is expressed in AC rms value and defined as the prospective or available short circuit current at the instance of short circuit. I_K" will be equal to the various fault current calculated using the method of symmetrical component as described in the previous section or using the per unit method or ohmic method or MVA method. I_K" is the basic building block for the calculation of the other fault current parameters of IEC 909.

$$I_K" = \frac{cV}{Z_E}$$

where Z_E - equivalent impedance at the fault location.
V - prefault phase to neutral voltage
c - voltage factor

TABLE 1 – Taken From IEC 909

Phase to phase voltage	Voltage Factor c	
	For maximum fault current calculation	For minimum fault current calculation
35kV to 230kV	1.10	1.00
1kV to 35kV	1.10	1.00
400 volts to 1000 volts	1.05	1.00
Less than 400 volts	1.00	0.95

I_P - Peak Short Circuit Current

It is expressed in AC peak value and defined as the maximum possible instantaneous value of the prospective or available short circuit current.

$$I_P = K\,\sqrt{2}\,I_K"$$

where K is dependent on the X/R ratio.

Table 2 – Derived From Equation in IEC 909.

X/R	K	I_p/I_K"
0.5	1.02	1.44
1	1.07	1.51
2	1.24	1.75
5	1.56	2.21
10	1.75	2.47
50	1.94	2.74
100	1.97	2.79
200	1.99	2.81

The value of I_P is very dependent on the X/R ratio. The larger the X/R ratio, the larger will be the value of I_P. The X/R ratio will be larger when the point of fault is closer to the source, as when near a power generating plant. The accurate calculation of I_P is therefore very dependent on accurate value of the X/R ratio of the source. As a quick estimate, the X/R ratio of the source will approximate the X/R ratio of the upstream transformer. For example, if the source is modelled as a 22kV source from PowerGrid, the X/R ratio at 22kV will approximate the X/R ratio of the upstream 2 x 75MVA transformers. This is equivalent to a 1 x 150MVA transformer whose typical X/R value is 42. The calculated value of I_P will determine the making rating of the circuit breaker.

I_b – Symmetrical Short Circuit Breaking Current

It is expressed in AC rms value and defined as the integral cycle of the symmetrical AC component of the available fault current at the instant of contact separation of the first pole of the circuit breaker. The value of I_b will depend on the minimum time delay of the circuit breaker. The minimum time delay is the sum of the shortest possible operating time of the instantaneous relay and the shortest opening time of the circuit breaker. A typical value for the minimum time delay will be 60 msec., which consist of 40 msec. opening time for the circuit breaker and 20 msec. operating time of the instantaneous relay. A larger value of minimum time delay will result in a smaller value of I_b. This is because of the decay of the DC and AC component of the fault current, which will lead to a smaller value of I_b. The calculated value of I_b will determine the breaking rating of the circuit breaker.

Table 3 – Variation of Ib For Various Minimum Time Delay Of The Circuit Breaker

	Value of I_b/kA			
	t_{min} = 60 msec	t_{min} = 70 msec	t_{min} = 80 msec	t_{min} = 90 msec
3 Phase fault at 22kV of Figure 5	11.83	11.82	11.80	11.79
3 Phase fault at 6.6kV of Figure 5	8.10	8.07	8.04	8.01
3 Phase fault at 400 volts at Figure 5	23.66	23.57	23.49	23.41

I_{dc} – DC Component of the Fault Current

The DC component of the fault current is calculated based on a factor of I_K".

$$I_{dc} = \sqrt{2} \exp\left(\frac{-2\pi f Rt}{X}\right) I_K"$$

where f - system frequency
t - time duration

Figure 2 is the graphic illustration of I_{dc}.

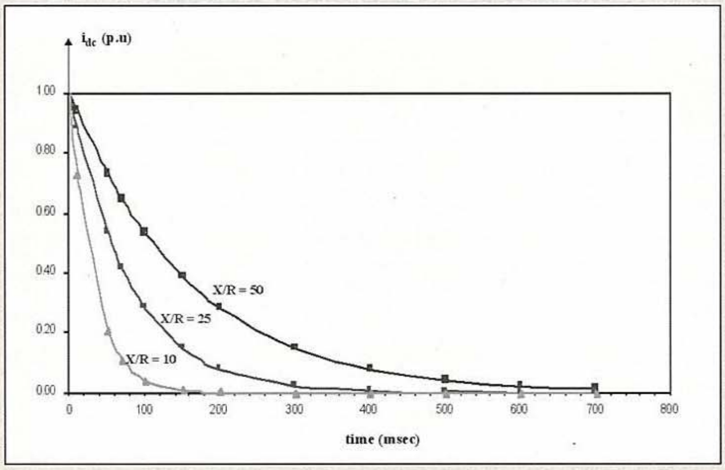


Figure 2: DC Component of fault current

The DC component will eventually decay to zero. The calculated value of I_{dc} shall be less than the % DC component of the test voltage specified in IEC 56 for the breaking test of circuit breakers.

Table 4 – From IEC 56

Sequence	Symmetrical current	DC Component
1	10%	Less than 20%
2	20%	Less than 20%
3	30%	Less than 20%
4	40%	Less than 20%
5	50%	Less than 30%

I_k – Steady State Fault Current

This is the value of fault current when all transient components, both AC and DC, have decayed to zero. The value of I_K will largely depend on the parameters of the generator, where the rated current and excitation voltage are the more important parameters.

$$I_K = \lambda\ I_G$$

where I_G - rated current of generator
λ - function of excitation voltage of the generator and other parameters of the generator.

A fault near a generator is an example of a near to source fault. In such a situation, the dominant impedance will be from the generator, whose value will increase with time. The impedance of generator is broadly classified into three time frames:

- subtransient period of less than 20ms
- transient period of up to 500 ms
- steady state period of more than 500 ms

The successive effect of the three impedance will lead to a gradual reduction in the fault current. The value of I_b will largely be inductive in nature and of low power factor. Therefore it will be the field circuit of the generators that will determine the magnitude of I_b. The MW rating of a field circuit is typically a small percentage of the MW rating of the generator and it will be possible for the value of I_k to be less than the full load current of the generator.

Comparison of Circuit Breaker Rating and IEC 909

Using the criteria defined in IEC 909, the ETAP software will automatically decide whether a fault location is near to source or far from source. The implication will be in the values of I_K", I_b and I_K.

In a far from source fault, we have

$$I_K" = I_b = I_K$$

In a far from source fault, we have

$$I_K" > I_b > I_K$$

An alternative interpretation of a near to source fault current and far from source fault current is to examine the AC and DC component of the fault current:

- near to source fault current = AC component (will vary) + DC component (decay to zero)
- far from source fault current = AC component (will not vary) + DC component (decay to zero)

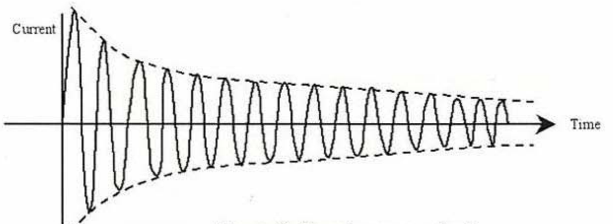


Figure 3: Near to source fault

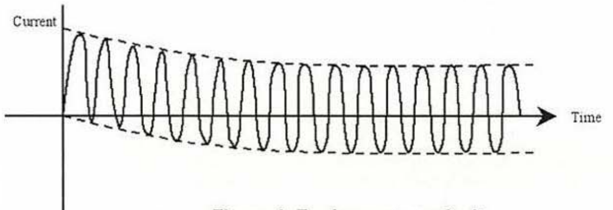


Figure 4: Far from source fault

Figure 3 and 4 are the graphic illustration of both fault current. At both fault locations, the calculated value of I_b will determine the breaking rating of the circuit breaker. Typical values are 12.5, 15, 20, 25, 31.5, 40, 50 and 63KA.

The other important parameter of IEC 909 is I_p. The calculated value of Ip will determine the making rating of the circuit breaker. Typical values are 31.5, 40, 63, 80 and 100kA.

In summary, we have

Device rating	Compare with IEC 909	Unit
Breaking	I_b	RMS value
Making	I_p	Peak value

Table 5 : Fault at 22kV of Figure 5

	Fault Current in KA			
	I_k''	I_p	I_b	I_k
3 Phase Fault	12.09	32.60	11.83	9.71
Single phase to Earth Fault	3.72	10.04	3.72	3.72
Line to Line Fault	10.47	28.24	10.47	10.47
Double phase to earth fault	11.42	30.81	11.42	11.42

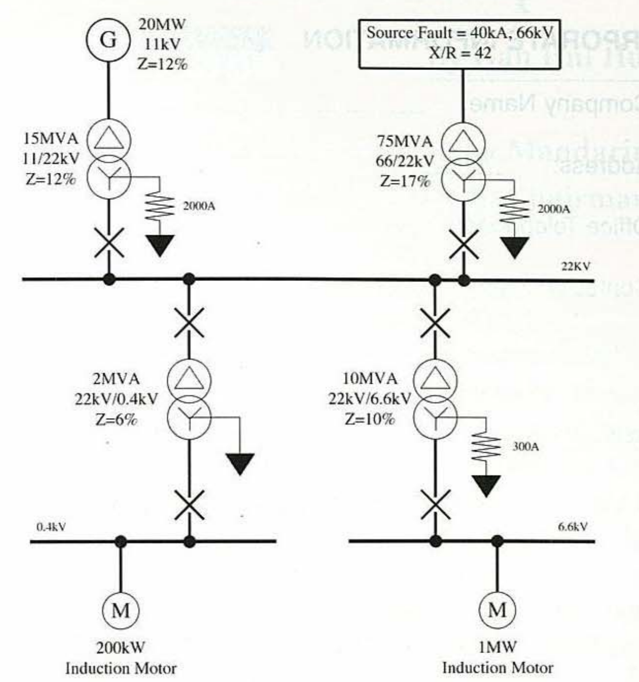
Table 6 : Fault at 6.6kV of Figure 5

	Fault Current in KA			
	I_k''	I_p	I_b	I_k
3 Phase Fault	8.46	21.86	8.10	6.38
Single phase to Earth Fault	0.33	0.85	0.33	0.33
Line to Line Fault	7.33	18.93	7.33	7.33
Double phase to earth fault	7.41	19.14	7.41	7.41

Table 7 : Fault at 0.4kV of Figure 5

	Fault Current in KA			
	I_k''	I_p	I_b	I_k
3 Phase Fault	25.02	55.05	23.66	18.05
Single phase to Earth Fault	23.79	52.36	23.79	23.79
Line to Line Fault	21.67	47.68	21.67	21.67
Double phase to earth fault	24.92	54.84	24.92	24.92

Figure 5



Calculation Example

Figure 5 is the single line of an electrical installation with embedded generation, 66kV connection to the utility and loads at 6.6kV and 400 volts. The utility has a three phase fault level of 40kA at 66kV and X/R ratio of 42. The utility earthing is through a resistor which limits the single phase to earth fault to 2000A. Fault contribution from the 6.6kV induction motor and 400 volts induction motor was taken into consideration. The embedded generator is a gas turbine generator with a sub-transient reactance of 12%. The results from the Etap Software are summarized in the table 5, 6 and 7 for the various fault locations and various fault current. During a fault, the induction motors contribution to the fault current is only to I_K''. However the absence of a sustained field excitation system will mean that these values of I_K'' contribution from the induction motors cannot be sustained and will decay to zero after a few cycles. This will translate to a lower value of I_b as compared to I_K'' .

Conclusion

The use of software for fault current calculation is a necessary productivity tool. The fault current for all possible configuration of the network can be instantaneously calculated by the software. Any attempt to manually calculate by hand will be time consuming and may be prone to error.

Reference

1. William D. Stevenson, Elements of Power System and Analysis.
2. IEC 909 - Short circuit current calculation in three phase AC system.
3. IEC 56 - High Voltage AC circuit breakers.
4. Manual for ETAP Software, Version 4.7