# Comparison of ANSI and IEC 909 Short-Circuit Current Calculation Procedures

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*Abstract*— **Although ANSI fault calculation methods are designed to determine a value to compare with the equipment ratings, the IEC 909 Standard presents a method that inherently more accurately models the fault currents that flow. The IEC method requires significantly more complex modeling of the power system fault contributions than ANSI requires. By understanding the calculation differences, the difference in equipment ratings becomes more insightful.**

## I. Introduction

In THE EMERGING world marketplace, engineers should be familiar with the basic differences between the American National Standards Institute (ANSI) and International Electrotechnical Commission-909 (IEC 909) short-circuit calculation procedures. With the removal of trade barriers in the European Community in 1992, the globalization of electrical manufacturers, and the expansion of the engineering marketplace to new countries around the world, engineering firms able to cross international borders will gain a competitive edge.

Both the IEC and the ANSI standards for short-circuit current calculation procedures were developed to provide conservative results for determination of the capacity or rating of electrical equipment. Additionally, the IEC 909 Standard provides procedures for determining minimum short-circuit currents to be used as the basis for selecting fuses, setting protective devices, and checking the run-up of motors.

The IEC 909 procedure requires significantly more detailed modeling of the power system short-circuit contributions than does the ANSI. It should be mentioned that even though both standards provide detailed procedures for the calculation of short-circuit currents, they do not exclude the possibility of alternate methods if the alternate methods give at least the same precision. However, neither standard specifically identifies these alternate methods, thus laying the burden of proof on the engineer.

The ANSI standards that currently apply to equipment rating values include C37.010 for systems 1000 V and above and C37.13 for systems below 1000 V. The ANSI/IEEE Standard 141-1986 (the *IEEE Red Book*) provides supplemental guidelines and interpretation of these ANSI standards.

The first edition of the IEC 909 Standard (1988) is derivative work taken from the German Verband Deutscher Electrotechniker (VDE) Standard. This standard applies to all voltages up to 230 kV operating at nominal frequency (50 or 60 Hz). This standard is supplemented by the proposed draft Standard IEC/TC 73 that provides supplementary documentation for explanation and derivation of the factors used in the IEC 909 publication.

The following sections present a generalization of the methods used by both standards. The philosophical differences in calculation procedures are discussed. No attempt is made here to present the complete method of either standard or to make judgements on the correctness of either standard.

## II. Ansi Impedance-Based Calculations

The method of short-circuit calculations provided by the ANSI standards is best described as impedance based. Strict interpretation of the ANSI standards requires separate network solutions for 1) the low-voltage impedance network, 2) the medium- and high-voltage momentary impedance network, and 3) the medium- and high-voltage interrupting impedance network. Each of these three networks is different. The following paragraphs outline the differences of the impedance networks.

The low-voltage standard requires that all machines, including all sizes of induction motors, be included as part of the impedance network. For this standard, the machine subtransient impedances are used for all machines. For the low-voltage network, symmetrical currents are calculated for comparison with equipment ratings. If the $X/R$ ratio at the short-circuit location exceeds a value of 6.6, then multiplying factors are applied to the symmetrical rating to arrive at a number that can be compared with the tested value of the low-voltage breakers. There are additional factors that may enter into the direct comparison of the calculated numbers before they are compared with the equipment.

For the closing and latching (momentary) network, the ANSI C37.010 Standard requires the use of various multiplying factors for the subtransient reactance. A factor of 1.2 is used for induction motors from 50 to 1000 hp at 1800 r/min or less and for induction motors from 50 to 250 hp at 3600 r/min. The standard also permits neglecting all motors below 50 hp as well as all single-phase motors. Using these impedances to represent the machines, this momentary network is used for calculating the closing and latching duty for all high-voltage circuit breakers rated on a symmetrical current basis. This close-and-latch value is equivalent to the half-cycle current. The value is calculated as an rms value of an asymmetrical current and depends on an $X/R$ ratio at the short-circuit

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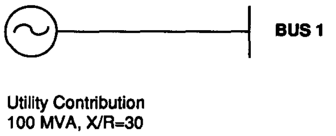

Fig. 1. Simplified power system.

location, which must be determined by separately reduced $R$ and $X$ networks. The *Red Book* permits the momentary network to be used for the low-voltage network, thus reducing the calculation complexities.

The interrupting network for the ANSI C37.010 Standard requires the use of various multiplying factors for the resistance and reactance networks. A factor of 1.5 is used for induction motors above 1000 hp at 1800 r/min or less and for induction motors from 50 to 250 hp at 3600 r/min. A factor of 3.0 is used for all other induction motors. A factor of 1.5 is also used for all synchronous motors. Using a network with machines represented by these impedances, rms currents are calculated. The rms currents calculated, along with the separately reduced $X/R$ values, and various curves contained within the standard are used to arrive at interrupting currents.

The C37.010 Standard recommends the use of separate resistance and reactance networks for determination of $X/R$ ratios used for the momentary and interrupting current calculations. This standard also provides some empirical rules for determination of local and remote generation. The ac/dc decrements or dc decrements only are determined from the local/remote status of generators; the $X/R$ ratio is calculated by the separate network reduction techniques. For all points in time, the impedance multipliers for the induction and synchronous machines remain fixed for the interrupting duty calculations. This equipment is assumed to have the same impedance calculation for breakers opening at two cycles or at some other delayed value.

Having modified the contribution impedance values to simulate the momentary and interrupting equivalent networks, ANSI calculates an rms current. This value of current is then used to calculate the momentary and interrupting equipment ratings.

ANSI interrupting ratings deserve closer examination. The actual interrupting rating for equipment is determined by applying multiplying factors (which are taken from graphs presented in the standard) to the calculated interrupting rms current. It is interesting to note that as the opening time of breakers is increased, the ANSI standards require a higher interrupting rating for the breaker.

Fig. 1 illustrates a simplified power system with a remote utility source. In this circuit, it is assumed there is only a dc decay current factor.

Fig. 2 illustrates the ANSI interrupting ratings for the circuit in Fig. 1 at a constant $X/R = 30$. The multiplying factors are 1.097, 1.150, 1.135, and 1.185 for two, three, five, and eight cycle breakers taken from Fig. 10 on p. 36 of ANSI C37.010-1979 and Fig. 104 on p. 307 of IEEE Standard 141-1986. The figure also illustrates dc decay calculated using classical techniques.

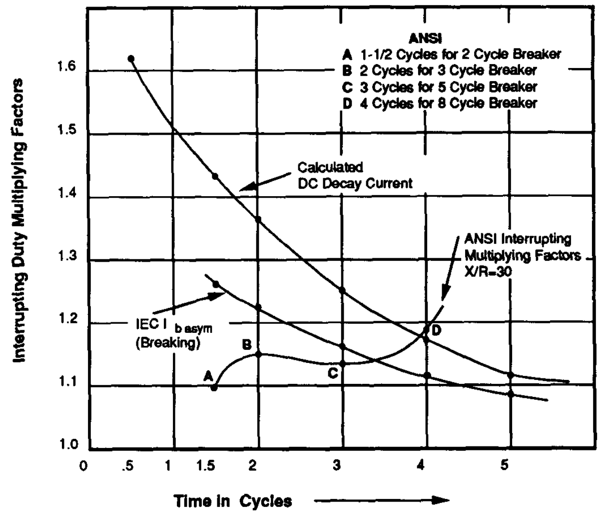

Fig. 2. ANSI and IEC interrupting ratings.

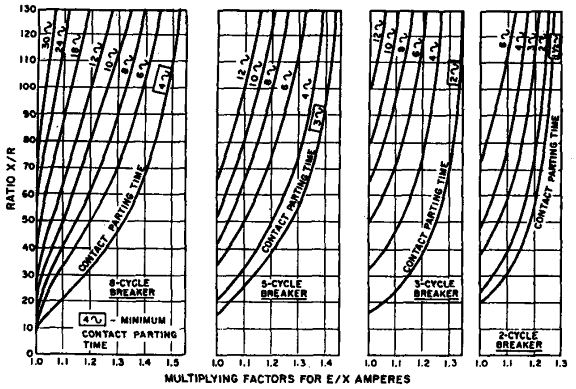

Fig. 3. ANSI decrement curves.

The graphs shown in Fig. 3 are taken from p. 36 of ANSI/IEEE Standard C37.010-1979. They are replicated here to demonstrate the interrupting factors illustrated in Fig. 2.

We can generalize about the solution methodology by observing that three different impedance networks are used: 1) the low-voltage, 2) the closing and latching, and 3) the interrupting. In addition, it is important to note that these impedance networks are used to obtain total currents at the short-circuit location; these total currents are then modified on a global basis to obtain the short-circuit currents flowing at various times. This standard does not attempt to model the preloading of the generators or to model in detail the varying decay rates of each individual motor and generator.

## III. IEC CURRENT-BASED CALCULATIONS

For each short-circuit location in the network, the IEC 909 Standard calculates a total initial symmetrical short-circuit rms current ($I''_k$) as well as the initial symmetrical short-circuit rms current at a synchronous machine ($I''_{kG}$) in each contributing source, as illustrated in Fig. 4. The network

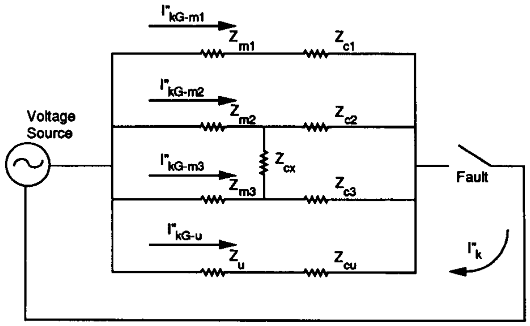

Fig. 4. IEC 909 requires calculation current flow from each source.

includes all contributing sources. These $I''_{kG}$ currents are important because they form the basis of determining 1) the instantaneous peak short-circuit current $i_p$, 2) the decaying dc (aperiodic) component of short-circuit current $i_{DC}$, 3) the symmetrical short-circuit breaking rms current $I_b$, 4) the asymmetrical short-circuit breaking rms current $I_{b\,asym.}$, and 5) the symmetrical steady-state short-circuit rms current $I_k$ for each contributing source. Fig. 2 illustrates breaking currents for the circuit in Fig. 1.

The IEC 909 procedure requires calculating the contributing source's component of short-circuit current for each of the currents described above and then using these components to derive the short-circuit location's totals. To apply the equipment, it is necessary to know how these currents are distributed throughout the network. Therefore, it is necessary to track each contributing source's currents throughout the network to the short-circuit location, as illustrated in Fig. 4. These individual contributing source currents are each a function of the machine characteristics, the $R/X$ ratio that each contributing source sees to the short-circuit location, the minimum clearing time for breaker operation, the initial symmetrical short-circuit current, the type of excitation, and the determination as to whether the contributions flow through a meshed or nonmeshed network and whether the contribution is near or far from the short-circuit location. IEC 909 procedures treat each of the above factors differently for each contributing source.

## IV. ANSI LOCAL/ REMOTE VERSUS IEC 909 NEAR/FAR

ANSI makes no attempt to account for the remoteness of induction and synchronous motors during the calculation of interrupting currents. Motors are represented by fixed impedances as previously described. For generators, ANSI states that if the short-circuit location is more than two transformers away or if the transfer reactance between the generator and short-circuit location is greater than 1.5 times the subtransient reactance of the generator, the generation is considered to be remote. Otherwise, the generation is considered to be local.

The standard provides ac/dc decrement curves and dc-only decrement curves for determining multiplying factors that are applied on a global basis to the total short-circuit current. The choice of using the ac/dc decrement factor or dc decrement factor only is determined by whether the source contributions are predominantly local or predominantly remote. Recent IEEE papers have suggested that the ratio of remote contributions to total contributions (NACD ratio) should be used to interpolate between the dc-only decrement curves and the ac/dc decrement curves to determine a more accurate factor.

IEC 909 examines the magnitude of the $I''_{kG}$ currents that flow from each individual contributing source to the short-circuit location. For calculating breaking currents, motors are all considered near if the sum of all motors' $I''_{kG}$ currents exceeds 5% of the total $I''_k$ without motors. Otherwise, all motors are considered far. Asynchronous motors whose terminals are short circuited are treated as a special case. Synchronous machines are considered near if their $I''_{kG}$ current is greater than twice their rated current. Otherwise, synchronous machines are considered far.

Each motor or generator is treated individually for the application of decay factors. For synchronous machines, these factors are a function of the minimum breaker clearing times and the ratio of the machine's contribution short-circuit current contribution $I''_G$ to the machine's rated current. To address the faster decay rates of asynchronous machines, an additional decay factor that is a function of the machine's rated active power per pole pair is used.

## V. CONTRIBUTION DATA

From the above discussion, it is apparent that calculation procedures of each standard require the typing of source contributions into different categories. These categories include induction or asynchronous motors, synchronous motors, generators or synchronous generators, and utility or network feeders. Data required for representing these contribution types varies slightly between the ANSI and the IEC 909 Standards. Some of these differences are briefly noted below.

For asynchronous motors, ANSI requires information on r/min and hp rating for determining the subtransient reactance multiplying factors. IEC 909 requires information on rated real power per pole pair for determining decay rates.

For synchronous machines, IEC 909 requires additional information on rated power factor in order to calculate the correction factor for synchronous machines ($k_G$ factor) used to account for machine initial loading conditions. The IEC 909 also requires additional information on the type of excitation and $X_{dsat}$ (reciprocal of the short-circuit ratio) in order to calculate the steady-state current $I_{kG}$. The IEC 909 Standard defines an additional contribution type that is not directly found in the ANSI Standard. The power station unit (PSU) consists of a generator and a transformer treated as a single entity. The IEC 909 Standard contains separate procedures for short-circuit calculations, depending on whether the short-circuit location is between the generator and the transformer or whether the short-circuit location is on the load side of the transformer.

## VI. TRANSFORMER MODELS

The IEC 909 Standard contains procedures for modeling transformers whose primary and secondary rated voltages may not be the same as the system's voltage levels. These procedures are addressed with regard to the modeling of power station units and are further expanded on by the examples contained in Appendix A (p. 109 of IEC 909 Standard). Every transformer (18 total) in these examples contains rated voltages that are different from the system voltage levels, that is, the transformer nominal turns ratio is different from the ratio of system voltage levels. The intent of the IEC 909 Standard to model this condition is obvious, but it fails to address the general problem of finding transformers of unequal turns ratios anywhere in the system and not just at radial fed locations. This problem is further complicated by the current-based procedures of the IEC 909 Standard, regardless of whether the solution is performed using ohmic or per-unit quantities. The ANSI Standard does not specifically discuss solution of the network, thus leaving the engineer to solve these problems.

## VII. PREFAULT VOLTAGES

Normally, ANSI Standard fault calculations are performed at a nominal 1.0 per unit voltage. If actual operating voltages are less than or greater than a breaker's rated maximum voltage, the breaker's rated short-circuit current may be adjusted within the range of the correction factor for impedances (K factor).

The IEC 909 Standard requires the use of a voltage factor $c$ table (see Table I on p. 27 of IEC 909 Standard). This table specifies two sets of voltage factors that vary by voltage levels. One set of factors is used to determine maximum short-circuit currents, and the other set of voltage factors is used to determine minimum short-circuit currents. The use of these factors accounts for worst-case prefault voltage conditions, the effects of off nominal transformer taps, and the effects of all line capacitances and parallel admittances of nonrotating loads except for those of the zero sequence system. These voltage factors are used for determining an equivalent voltage source at the short-circuit location so that the initial symmetrical short-circuit current can be calculated. A default set of voltage factors appears in Table I on p. 113 of the IEC 909 Standard and can be used for countries that have not yet standardized on a set of voltage factors.

## VIII. NETWORK CONFIGURATIONS

ANSI makes no direct reference on differences in calculation between radial and loop systems. This standard does state that the use of separate $R$ and $X$ networks used to calculate the $X/R$ ratio tends to correct for multiple time constants and associated decay rates due to short-circuit currents passing through multiple paths to the short-circuit location.

The IEC standards make a major effort to distinguish between short-circuit currents that flow through both meshed and nonmeshed networks. When contributions are supplied through a nonmeshed network only, the contributions are simply added (scalar or vectorially) to determine the total short-circuit current. For contributions flowing through meshed networks, the standards allow three different correctional methods of calculation.

*Method A:* If there is a uniform $R/X$ ratio, then use the factor taken from a standard figure (see Fig. 8 on p. 47 of IEC 909) using the smallest ratio of $R/X$ of all branches of the network. Here, it is only necessary to choose the branches that together carry 80% of the current at the nominal voltage corresponding to the short-circuit location. Any branch may be a series combination of several elements.

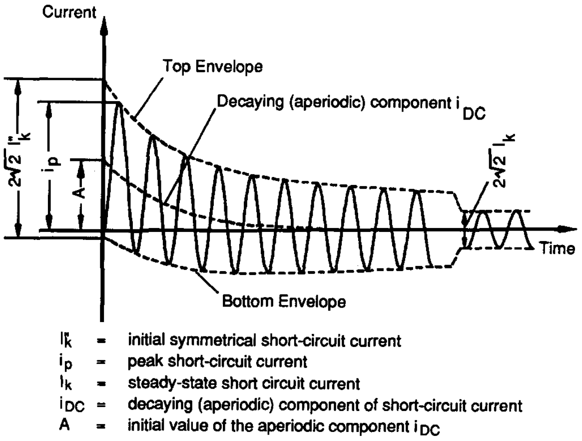

Fig. 5. Short-circuit current of a near-to-generator short-circuit (schematic diagram).

*Method B:* Determine a multiplying factor from Fig. 8 used in Method A based on the $R/X$ at the short-circuit location, and then multiply this value by 1.15 for safety reasons.

*Method C:* Calculate an equivalent frequency network to determine the multiplying factor. For a 60-Hz system, solve a complete new impedance network at a frequency of 24 cycles, and then, a number of complex ratios must be taken.

These correctional methods are used to determine the peak short-circuit current as well as the dc aperiodic current. The peak current multiplying factor may be determined from the IEC graph or from the following equation:

$$\text{peak current factor} = 1.02 + 0.98e^{-3R/X}$$

where $R/X$ is the resistance/reactance ratio.

## IX. CALCULATED DATA

ANSI C37.010 calculates an rms symmetrical current for the momentary network and states that if this current is below the rms rating of the breaker and the $X/R$ ratio is less than 15, then no additional calculations are required. If the $X/R$ ratio is greater than 15, then it is required to calculate the rms momentary (close and latch) current by using the ANSI simplified rule of 1.6 times the rms symmetrical current based on the momentary impedance network. Optionally, the standard permits a more accurate calculation based on the calculated $X/R$ value at the short-circuit location.

ANSI calculates a value of rms asymmetrical current for the interrupting network and uses this value with a multiplying factor to arrive at an interrupting duty, which is a function of the opening time of the breaker. Multiplying factors for the interrupting duty are determined from charts in the standard. The chart of choice is dependent on the local/remote status of the contributions to the short-circuit location.

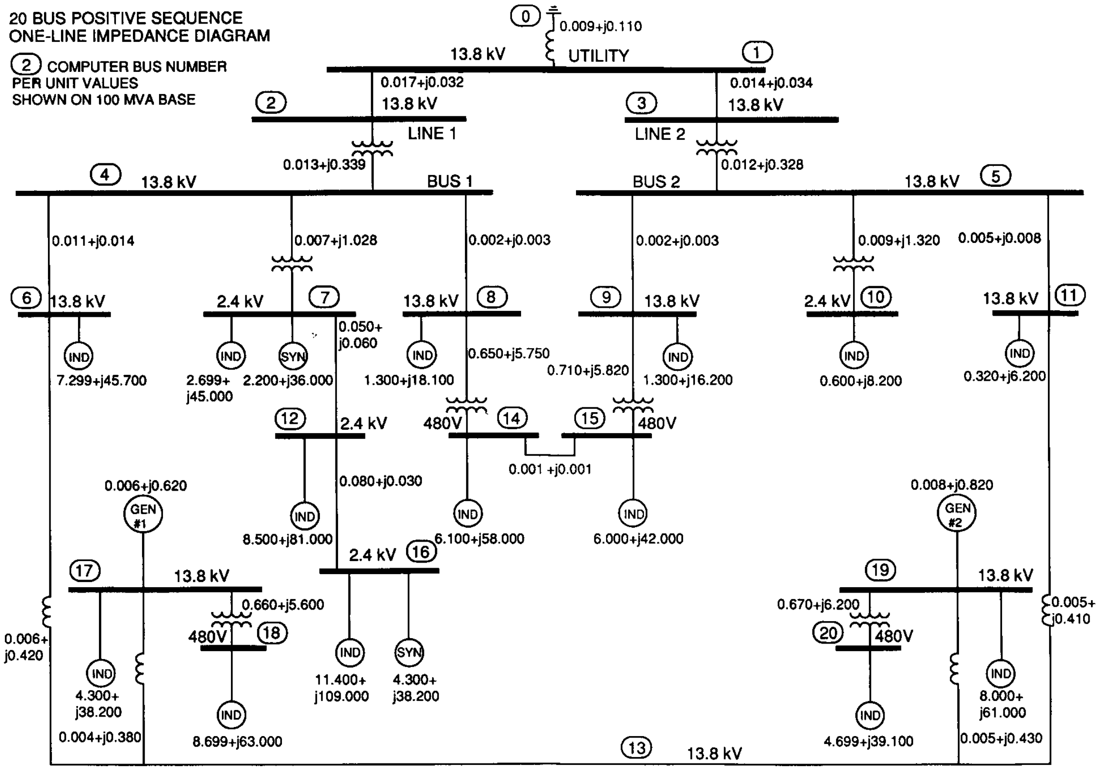

Fig. 6. One-line diagram for short-circuit calculations.

TABLE I
COMPARING CALCULATED RESULTS

| Bus No. | kV | ANSI X/R | ANSI E/Z Momentary rms kA | ANSI Momentary kA rating | ANSI E/Z Interrupting 5 Cycle Bkr kA | IEC $i_p$ kA | IEC $i_p/\sqrt{2}$ kA | IEC $I''_k$ kA | IEC $I_b$ kA | IEC $I_{b\ asym}$ kA |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 138.00 | 14.6 | 4.346 | 6.584 | 4.279 | 11.434 | 8.085 | 4.449 | 4.449 | 4.487 |
| 2 | 138.00 | 8.5 | 3.341 | 4.667 | 3.291 | 9.242 | 6.535 | 3.494 | 3.494 | 3.505 |
| 3 | 138.00 | 10.2 | 3.325 | 4.787 | 3.269 | 9.389 | 6.639 | 3.481 | 3.450 | 3.463 |
| 4 | 13.80 | 21.6 | 14.268 | 22.504 | 14.393 | 44.472 | 31.447 | 15.813 | 15.396 | 15.908 |
| 5 | 13.80 | 27.6 | 15.001 | 24.105 | 15.448 | 46.906 | 33.168 | 16.726 | 16.301 | 16.929 |
| 6 | 13.80 | 33.4 | 14.058 | 22.884 | 15.359 | 44.021 | 31.128 | 15.593 | 15.214 | 15.738 |
| 7 | 2.40 | 61.1 | 20.066 | 33.552 | 24.697 | 62.563 |  | 22.515 | 21.222 | 24.010 |
| 8 | 13.80 | 19.1 | 14.127 | 22.032 | 14.036 | 44.012 |  | 15.657 | 15.244 | 15.689 |
| 9 | 13.80 | 23.6 | 14.846 | 23.560 | 14.868 | 46.401 |  | 16.552 | 16.130 | 16.674 |
| 10 | 2.40 | 78.0 | 17.416 | 29.320 | 21.474 | 54.382 |  | 19.721 | 19.091 | 21.670 |
| 11 | 13.80 | 36.2 | 14.886 | 24.333 | 16.214 | 46.460 |  | 16.608 | 16.186 | 16.815 |
| 12 | 2.40 | 19.0 | 19.173 | 29.796 | 18.625 | 59.911 |  | 21.513 | 20.260 | 20.806 |
| 13 | 13.80 | 55.3 | 16.489 | 27.507 | 19.704 | 53.311 |  | 19.030 | 18.741 | 20.509 |
| 14 | .48 | na | na | 61.328 | na | 124.888 |  | 45.788 | 43.731 | 43.783 |
| 15 | .48 | na | na | 61.327 | na | 124.712 |  | 45.789 | 43.731 | 43.783 |
| 16 | 2.40 | 9.2 | 18.665 | 26.292 | 17.515 | 58.036 |  | 20.938 | 19.712 | 19.769 |
| 17 | 13.80 | 81.7 | 12.688 | 21.423 | 15.860 | 42.568 |  | 15.239 | 15.027 | 17.594 |
| 18 | .48 | na | na | 31.010 | na | 58.033 |  | 23.245 | 22.421 | 22.437 |
| 19 | 13.80 | 80.8 | 10.822 | 18.267 | 13.533 | 37.182 |  | 13.313 | 13.188 | 15.391 |
| 20 | .48 | na | na | 28.708 | na | 53.366 |  | 21.240 | 20.393 | 20.418 |

The IEC 909 Standard calculates both minimum and maximum fault currents for the following:

1) Initial symmetrical short-circuit current $I''_k$
2) peak short-circuit current $i_p$
3) dc (aperiodic) short-circuit current $i_{DC}$
4) symmetrical short-circuit breaking current $I_b$
5) steady-state short-circuit current $I_k$
6) asymmetrical short-circuit breaking current $I_{b\,asym.}$.

Fig. 5 shows these components of short-circuit current graphically.

## X. COMPARING CALCULATION RESULTS

For a typical system shown in Fig. 6, Table I illustrates results of calculations by both the ANSI and IEC standards.

Table I illustrates calculated results using both standards for the same problem.

Fig. 6 is a typical power system design that has been used as a test problem for evaluation and comparison of ANSI software programs. This test problem is used here to compare ANSI results with IEC results.

## XI. CONCLUSIONS

The preceding sections have described important conceptual differences between ANSI and the IEC. Although ANSI simply applies multiplying factors to machine impedances to account for their ac decay in the power system, IEC calculates the initial current of each machine to the short-circuit location and then calculates the decay separately for each contribution based on these initial conditions. Additionally, ANSI makes no clear distinction between radial and loop network contributions, whereas the IEC does. ANSI models generators as local or remote depending on the impedance difference between the short-circuit location and the generator; IEC considers both motors and generators to be subject to near/far calculation differences.

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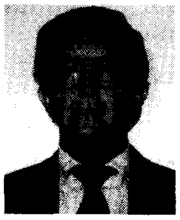

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