SIMULATING TRIPPING CHARACTERISTIC OF CIRCUIT BREAKERS USING LEAST SQUARE METHOD

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Abstract— Fault studies analysis an important part of power system analysis. The magnitude of the fault currents depend on the interval impedance of the intervening circuit. Fault current will be the problem in the network system which is it can damage the equipments. Fault studies are also used to obtain the rating of the protective devices. By using the protective devices, fault current which occurs at all bus will detect in the few second. This project is to describe the relation of rated fault current and trip time delay in different circuit breakers performance. The analysis of balance fault will develop by Matlab software version 7.6.

Keywords—Fault current, tripping time, insulated case circuit breaker (ICCB) and molded case circuit breaker (MCCB).

I. INTRODUCTION

The fault analysis usually might be the problem in the power system network. The components structure in power system network consisting by generators, transformers, busbar and also transmission line. The magnitude of fault currents depends on the interval impedance of generators combining with impedance of the intervening circuit. The component can be the one of the causes of the fault problem.

Normally, faults occur in power system due to either insulation failures, flashover, physical damage or human error. A power system is not static but changes during operation such as switching ON or OFF of generators and transmission lines and during planning such as addition of generators and transmission line. Sometimes, fault may also cause either short circuit to earth or between live conductors, or may be caused broken conductors in one or more phases.

Average annual fault for a typical large power system are as follows:

Equipment	Total of Fault (%)
Overhead lines	33
Cables	9
Switchgear	10
Transformers	12
Generators	7
Secondary Equipment	29
Total	100

Table 1: Annual Fault

The percentage distribution of faults also varies with the voltage. The data in Table 1 is for 13.8/132kV system. At 13.8kV, the value of fault may double and the value of fault of bus station may be halved.

II. THEORETICAL BACKGROUND

A. *Balanced Fault Analysis.*

Balanced fault analysis is defined as the fault that occurs in a power system when all three phase are short together. The situation can be explained in Figure 1.

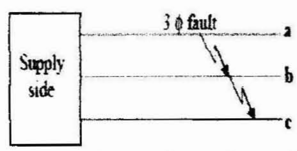

Figure 1: Balance three phase fault..

Short circuit level is defined as the reciprocal of equivalent reactance in the system computed from the references bus to the fault location [1]. Assumption should be made of the transformer connections since they are not giving any impact and sequence network which only using positive sequence.

B. Unbalanced Fault Analysis

Faults can occur as single faults at a single bus or as multiple faults at several buses. Symmetrical component allows unbalanced phase quantities and consider the phase sequence in three phase system. Positives sequence components consisting *abc* phase sequence. Negatives sequence components consisting *acb* phase sequence. Zero sequence components consisting of three phase components and all phase equal in magnitude. There are various types of unbalanced fault occurring in power system such as single line-to-ground fault, line-to-line fault and double line-to-ground Fault.

Single line to ground fault is consider a fault between phase *a* and ground through a fault impedance *Zf*, at fault bus shown in Figure 3. The line to ground fault required that positives, negatives and zero sequence network for phase *a*.

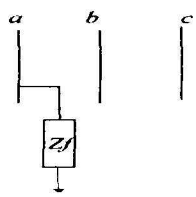

Figure 2: single line-to-ground fault

Line to line fault is consider a fault between phase b and c through the fault impedance *Zf*, at fault bus shown as Figure 4.

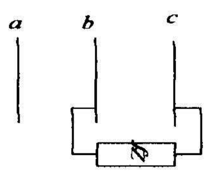

Figure 3: Line-to-line fault

Double line to ground fault is consider a fault between phase b and c through a fault impedance *Zf* to ground at fault bus as shown in Figure 5. Positive sequence impedance is placed in series with the parallel combination of the negative and zero sequence networks.

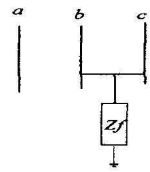

Figure 4: Double line-to-ground fault

The zero sequence equivalent circuit connections for the transformer should be considered because it will give the effect in calculating the current result. Fault studies are also used to obtain the rating of the protective devices. The higher fault levels recover by circuit breakers, so that fault current detector sometimes used.

C. Circuit Breakers Ratings

A circuit breaker is an electrical switch that automatically opens a circuit when certain electrical conditions are met. *ANSI* defines circuit breaker as a mechanical switching device, capable of making and carrying for a specified time and breaking currents under specified abnormal circuit conditions, such as those of a short circuit [2]-[3]. The rated fault current of a circuit breaker is the maximum current a circuit breaker can safely interrupt. The trip time delay setting of a circuit breaker relates to the performance of the circuit breaker over a period of time. It defines the ability of the breaker to remain closed for a time interval under high fault current conditions.

The components of a circuit breaker are frame or case made of metal or some type of electrical insulation, electrical contacts, arc extinguishing assembly, operating mechanism, trip unit, containing either thermal element, a magnetic element or both. The Figure 6 show how make the circuit trip. An armature links the contacts to the coil mechanism, which functions as an electromagnet. When the contacts are open, there is no current flow through the circuit breaker

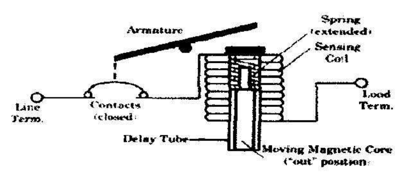

Figure 5: Contact close in circuit breaker

Tripping time curves are plots of the amount of fault current (vertical scale) flowing in the circuit to the time (horizontal scale) required for the breaker to clear the fault current. In this project, two types of circuit breakers are using to examine it with the power system network to discover the tripping time ratings of these circuit breakers. The circuit breakers used in this project are insulated case circuit breaker (ICCB) and molded case circuit breaker (MCCB).The curve of circuit breakers are shows in Figure Appendix 1-3. The data from the curve will transform to formula form using Least Square Method.

ICCB is a type of circuit breaker where assembled on a metal frame contained within an insulated case and is provided with air break contacts. These types of circuit breakers are used as a part of larger installations. The insulated case circuit breaker typically has a high short time withstand and high interrupting rating.

The fault current does not only occur at the generator buses where the transformer located. The fault current also happen at the another busses. In this IEEE 11-buses network, fault current also may occur at all busses but the value of fault current more lower than fault current at the generators. For MCCB, this rating with 400A is suitable to used at this busses because the interrupting current between 10 kA to 12 kA. These ratings are limited and current capabilities are lower than ICCBs.

III. METHODOLOGY

A test was conducted on the IEEE 11-bus power system network with the transformer connection as shown in Figure 7. The zero sequence network connections as show in Figure 8.

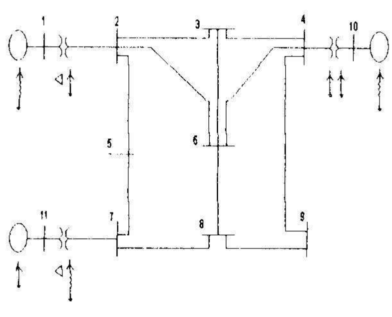

Figure 7: One line diagram of network system

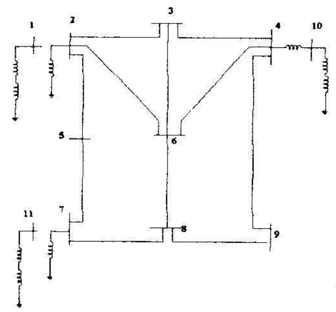

Figure 8: zero sequence network connections.

The main objective is to make an analysis on a total fault current in the system that occurs at busses and identify the circuit breakers depend on the tripping time performance. The procedure to achieve this objective is by referring the flow chart below.

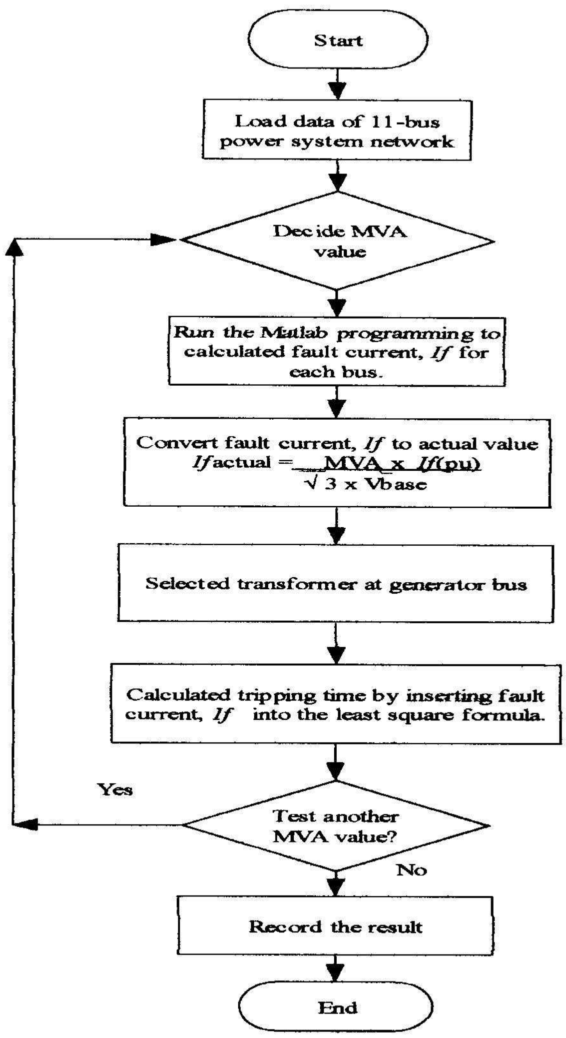

Figure 9: Flow programming process.

A. Fault Current in Balance Fault Network

The balanced faulted network can be solved conveniently by the *Thevenin's* method [4]. The fault is analyzed by changed on the impedance, *Zf* at the fault buses. *Thevenin's* theorem described that the changes network voltage will be effect by added fault impedance, *Zf* with all other sources are short circuit.

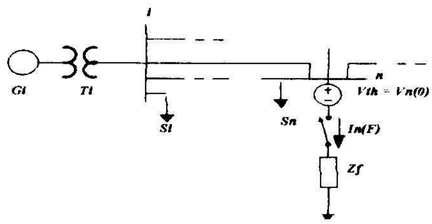

Figure 10: A typical bus of a power system.

Then we have bus, n equation

$$Vn(0) = Vn(F) + ZnnIn(F) \qquad (1)$$

From the *Thevenin's* circuit

$$Vn(F) = Zf\,In(F) \qquad (2)$$

Substitute (2) into (1) and find fault current:

$$In(F) = \frac{V_n(0)}{Z_{nn} + Zf} \qquad (3)$$

B. Fault Current in Unbalance Fault Network

The unbalanced fault is obtained by considering the sequence of network and various types of unbalanced fault.

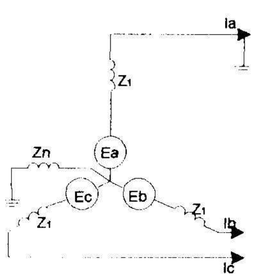

Figure 11: Single line-to-ground-fault on phase a.

Where

$$\begin{array}{ll} Va = 0 & Vb = Vc \neq 0 \\ Ib = Ic = 0 & Ia \neq 0 \end{array} \qquad (4)$$

The fault current is:

$$If = Ia = \frac{Ea}{Z_0 + Z_1 + Z_2} \qquad (5)$$

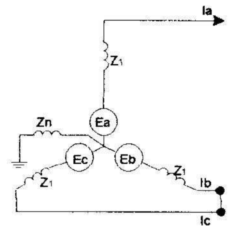

Figure 12: Line-to-line fault between phase b and c.

Where

$$\begin{array}{ll} Va \neq 0 & Vb = Vc \\ Ib = -Ic & Ia = 0 \end{array} \qquad (6)$$

The fault current is

$$If = Ia_1 = \frac{Ea}{Z_1 + Z_2} \qquad (7)$$

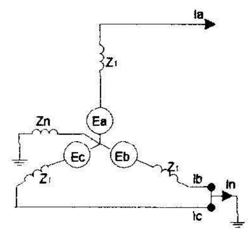

Figure 13: Double line-to-ground fault.

Where

$$\begin{array}{ll} Va \neq 0 & Vb = Vc = 0 \\ In = Ib + Ic & Ia = 0 \end{array} \qquad (8)$$

The fault current is:

$$Ia_1 = \frac{Ea}{Z_1 + \dfrac{Z_2 Z_0}{Z_2 + Z_0}} \qquad (9)$$

C. Method of Least Square

Least Square method is the one way to analyze the data of circuit breakers [5]. The circuit breakers are available with tripping time in second(s) which can relate with rated fault current, If. It is conveniently to obtain a relation between two variables for which a set of data information. Method of least square is not restricted to linear functions but also to polynomial functions. Some transformation must be used in polynomial functions so that a linear relation can be obtain. In this project, the transformation can be used is

$$y=Ae^{Bx} \quad (10)$$

1. INSULATED CASE CIRCUIT BREAKER ANALYSIS

The tripping time (s) and rated fault current for this circuit breaker are shows in the Table 2.

Current (A)	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
Time (t)	1000	400	150	70	30	7	5	0.8	0.5	0.35
ln Y	6.91	5.99	5.01	4.249	3.4	1.95	1.61	-0.2	-0.69	-1.05

Table 2: Tripping time and fault current for ICCB

By using the transformation, the calculation to get the curve for this circuit can be more efficient.

$$y=Ae^{Bx}$$
$$\ln y = \ln Ae^{Bx}$$
$$\ln y = \ln A + \ln e^{Bx}$$
$$= \ln A + Bx \ln e$$
$$\ln y = \ln A + Bx$$
$$Y=\alpha_o+\alpha_1 x \quad (11)$$

For normal equation:

$$n\alpha_o + \alpha_1\Sigma_i = \Sigma y_i$$
$$\alpha_o\Sigma x_i + \alpha_1\Sigma xi^2 = \Sigma x_i y_i \quad (12)$$

In matrix form,

$$\begin{bmatrix} n & \Sigma x \\ \Sigma x & \Sigma x^2 \end{bmatrix}\begin{bmatrix} \alpha_0 \\ \alpha_1 \end{bmatrix} = \begin{bmatrix} \Sigma y \\ \Sigma xy \end{bmatrix} \quad (13)$$

Where:
n = total number of variable
Σx = total summation of independent variable, x
Σx^2 = total summation of square value in independent variable, x
Σy = total summation of dependent variable, y
Σxy = total summation of independent variable, x multiply with dependent variable, y.

Calculate the value of α_o and α_1 using the inverse matrix technique and substitute the result into equation (13). Finally the formula of the curve for this circuit breaker can be obtained.

$$y = Ae^{Bx}$$
$$= \mathbf{2783.321^{-0.0009682x}}$$

This formula can be convert to the curve form by analyze it in Microsoft Excel to get the smooth plotted as in Figure 14.

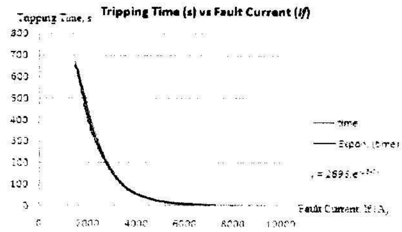

Figure 14: ICCB curve.

2. MOLDED CASE CIRCUIT BREAKER rating 400A

The tripping time (s) and rated fault current for this circuit breaker are shows in the Table 3.

Current (A)	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
Time (t)	120	12	3	1	0.2	0.1	0.09	0.03	0.02	0.015
ln Y	4.79	2.48	1.1	0	-1.6	-2.3	-2.4	-3.5	-3.91	-4.2

Table 3: Tripping time and fault current for MCCB

All the calculation to get the formula of the curve for this circuit breaker type is the same method as the previous circuit breaker following by the equation from (10) until (13). Finally the formula of the curve for this circuit breaker can be obtained.

$$Y = Ae^{Bx}$$
$$= \mathbf{76.54^{-0.0009659x}}$$

This formula can be convert to the curve form by analyze it in Microsoft Excel to get the smooth plotted as in Figure 15.

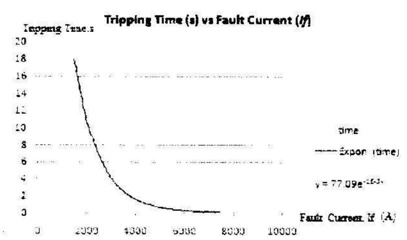

Figure 15: MCCB curve

D. Developed Programmings

The analysis of balance fault will develop by *Matlab* version 7.6. This programming should be starting by declaration of *Zdata* where the argument of *Zdata* is nbus x 4 matrix containing the impedance data of 11 element network. The *Zbuilt* functions to obtain the bus impedance matrix by the building algorithm method. The function is considered when all branches connected to the reference node (fault bus). The impedance will be the summation of resistor, R and the reactance, X in the solid fault condition [7]. All the functions of program will combine together to completed the programming codes. When programming is executed, it needed the user to enter the MVA value and the fault impedance, *Zf*.

IV. RESULTS AND DISCUSSION

A. Result

A fault current can be obtained by testing the IEEE 11-bus power system network shows in figure 7. Fault current represents by the value of addition impedance at the fault place. The analysis considered the fault impedance is zero, which is referred as solid fault [7]. The result for balanced fault shows in the Table 4 and for unbalanced fault shows in Table 5.

S base (MVA)	From Bus	To Bus	Fault Current (pu)	Fault Current (A)	Tripping Time (s)	
					ICCB	MCCB
150	1	F	1.5273	9584.3569	0.2718	0.0073
	10	F	1.6205	10169.5217	0.1508	0.0041
	11	F	1.4697	9223.1804	0.3908	0.0103
200	1	F	1.5273	12779.1425	0.0109	0.0003
	10	F	1.6205	13559.3623	0.005	0.000157
	11	F	1.4697	12297.5739	0.0177	0.000531

Table 4: Result for generator's bus in balanced fault analysis

Sbase (MVA)		150			200		
Fault Bus		1	10	11	1	10	11
Single Line To Ground	Phase a (pu)	1.3278	1.7091	1.3885	1.3278	1.7091	1.3885
	Phase b (pu)	0	0	0	0	0	0
	Phase c (pu)	0	0	0	0	0	0
	Fault Current (A)	8332.8961	10725.3442	8713.8143	11110.5281	14300.4589	11618.4191
Tripping Time (s)	ICCB	0.9571	0.0862	0.6524	0.0585	0.0024	0.0351
	MCCB	0.0245	0.0024	0.0169	0.0017	0	0.001
Line to Line Fault	Phase a (pu)	0	0	0	0	0	0
	Phase b (pu)	1.3229	1.4038	1.2731	1.3229	1.4038	1.2731
	Phase c (pu)	1.3229	1.4038	1.2731	1.3229	1.4038	1.2731
	Fault Current (A)	8301.7174	8809.7472	7989.0913	11068.9565	11746.3297	10652.1217
Tripping Time (s)	ICCB	0.9875	0.5924	1.3525	0.061	0.0309	0.0928
	MCCB	0.0252	0.0154	0.0341	0.0017	0.0009	0.0026
Double Line to Ground	Phase a (pu)	0	0	0	0	0	0
	Phase b (pu)	1.4473	1.6695	1.433	1.4473	1.6695	1.433
	Phase c (pu)	1.4473	1.6695	1.433	1.4473	1.6695	1.433
	Fault Current (A)	7369.5352	11341.5835	8256.3005	9826.0469	15122.1114	11008.4007
Tripping Time (s)	ICCB	2.5225	0.0464	1.0337	0.2131	0.001	0.0649
	MCCB	0.062	0.0013	0.0263	0.0058	0	0.0018

Table 5: Result for generator's bus in unbalanced fault analysis.

B. Discussion

From the result, we can see the fault current is increase when the MVA values are increase. The short circuit capacity or short circuit MVA at bus n is defined as the magnitudes of the rated bus voltage and the fault current. The base current is given by

$$Ib = \frac{Sb}{\sqrt{3}xVb}$$

Since the fault current in per unit does not change with the changing of MVA value but after the fault currents are convert in actual value, it also change follow by the increasing of MVA values. So, the current is proportional with the Sbase value. One way to test the effects of fault current is to express by the Sbase value at system and the result will show the changes in fault current magnitude for the system. Figure 16 shows the analysis of fault current depend on Sbase values.

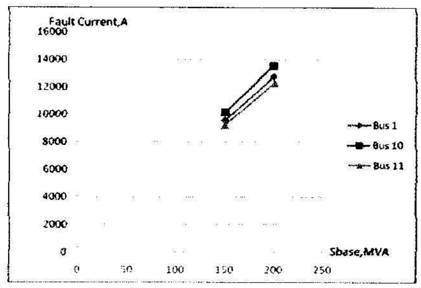

Figure 16: Fault Current vs Sbase value

Current interruption grading through transformer impedance more higher than the other location. The distribution of transformer faults depend its type and rating. The fault maybe causes by internal transformer fault such as short circuit between several turns of winding, poor electrical connection of conductors, breakdown of insulation of lamination or rise of temperature even below full load operation. Large frame circuit breakers like ICCBs are usually applied for this high interrupting current. These devices are capabilities to detect the fault in the short time with the high current until 15kA. Small frame circuit breaker like MCCBs can protect the equipment at the rating 400A. This devises suitable used at the bus with the lower fault current for bus number 2 to bus number 9. Figure 17 will illustrate this fault condition at the certain bus.

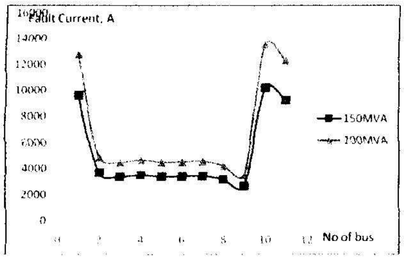

Figure 17: Fault current vs No of bus

The circuit breaker ratings show the relation between fault current and tripping time is inversely proportional. The circuit breakers capable to detect the large value of fault current more faster than the lower fault current value. The circuit breaker can open the circuit only in a few millisecond. It defines the ability of the breaker to remain closed for a time interval under high fault current conditions show in the Figure 18. This situation can give best solution for the system to maintaining the protection of the equipment and environment.

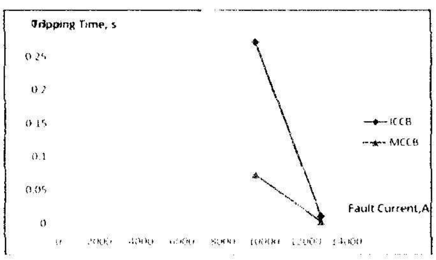

Figure 18: Tripping time vs fault current

V. RECOMMENDATION

In some case, it is desirable to use series ratings of circuit breakers. For example, the circuit breaker cannot detect the fault over this device's rating. Two or more circuit breakers applied in series can be safety applied at location in power systems were available fault current exceeds the rating of performance of circuit breaker alone. Protection devices in series can be set to delay tripping in order to coordinate with other devices having exceeding their rating to clear the fault current.

VI CONCLUSION

The objectives of this project are completely achieved. Performance of circuit breakers which suitable to insert in power system network is the highly effective solutions to control the fault problem in the electric network. Circuit breaker will trip when the electrical current through the sensing devices exceeds an established current rating. This project also show the relation between the fault current and trip time in second using graphed which display trip time delay curves. From the graph, will present how fast the circuit breaker will detect the fault. A good understanding of interrupting current capacity and short time delay rating allows the electrical engineer to make a selection of various types of circuit breaker designs.

ACKNOWLEDGEMENT

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APPENDIX

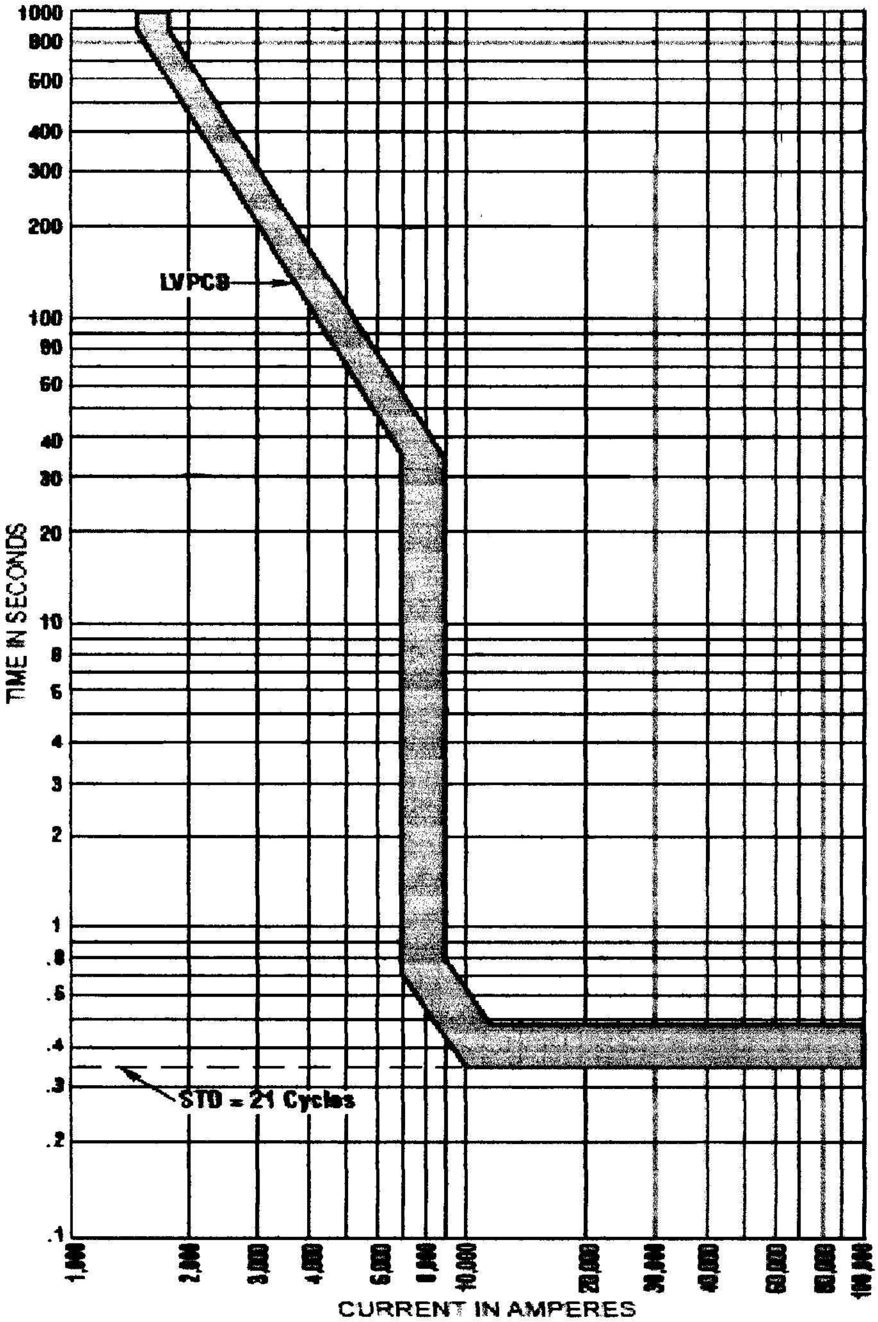

Figure Appendix 1: LVPCB Time-Current Curves [6]

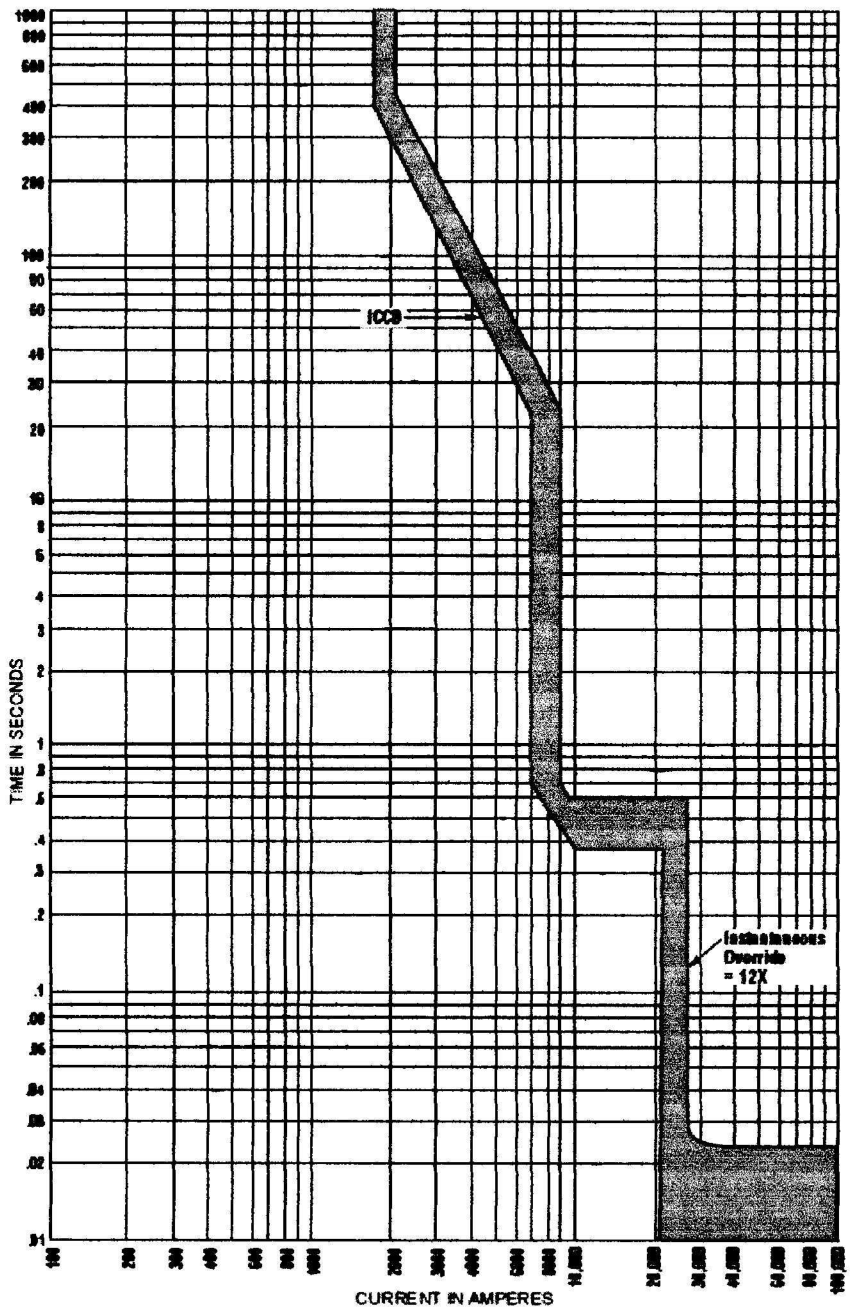

Figure Appendix 2: ICCB Time-Current Curves [6]

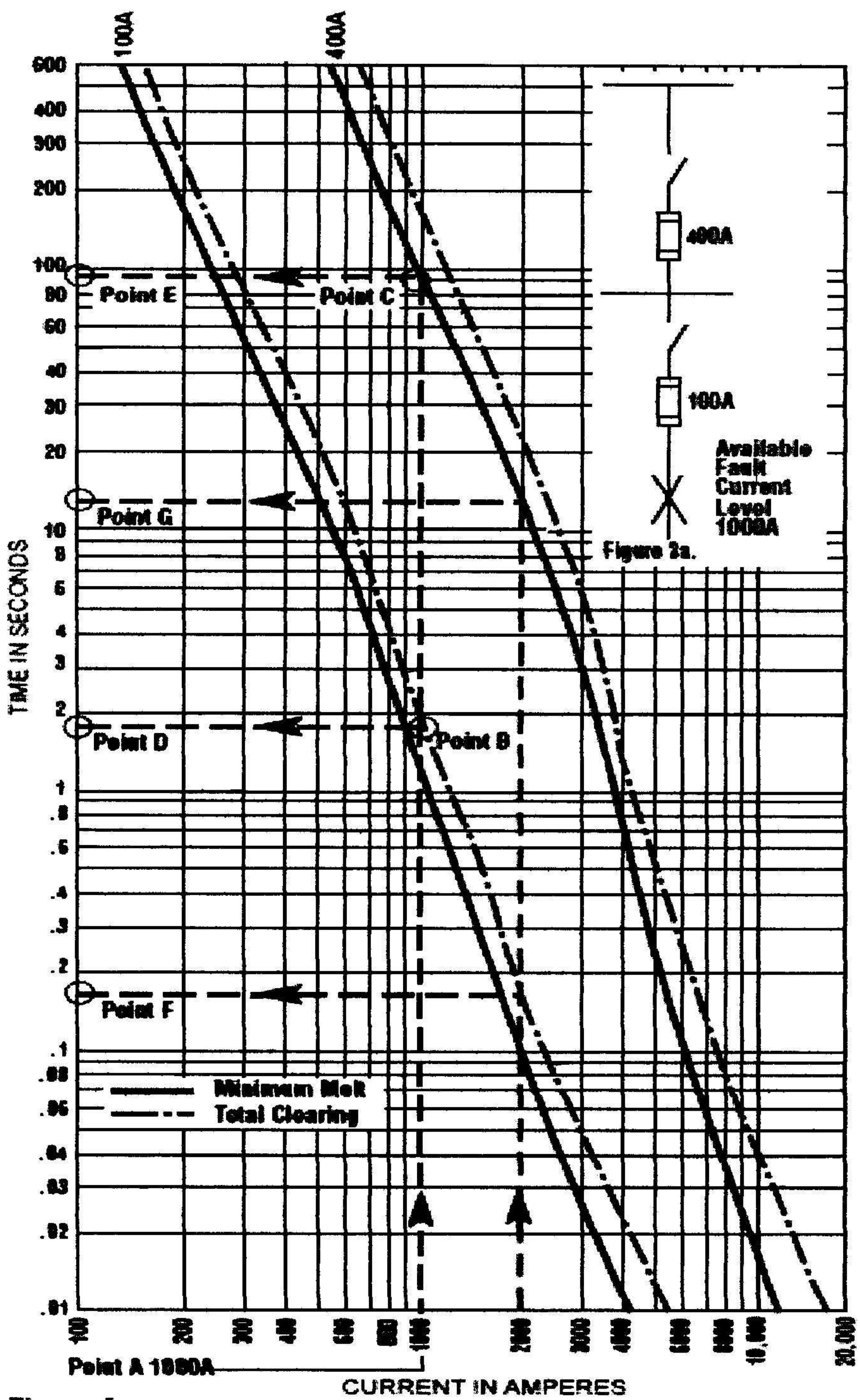

Figure Appendix 3: MCCB Time-Current Curves [6]