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SHORT CIRCUIT ANALYSIS OF ELECTRICAL DISTRIBUTION SYSTEM FOR INDUSTRY APPLICATION USING ETAP SOFTWARE

Manu K S[1], Dr. C Santhana Lakshmi[2], Dr. S Purushotham[3], Dr. V Shanmugasundaram[4], Dr. R Satheesh[5]

[1]*Manu K S: Student, Dept. of EEE, SCT, Salem, Tamil Nadu, India*
[2]*Dr. C. Santhana Lakshmi (co-author): Assist Professor (Sr Gd) Dept. of EEE, SCT, Salem, Tamil Nadu, India*
[3]*Dr. S. Purushotham (co-author): Assist Professor, Dept. of EEE, SCT, Salem, Tamil Nadu, India*
[4]*Dr.V. Shanmugasundaram (co-author): Assist Professor, Dept. of EEE, SCT, Salem, Tamil Nadu, India*
[5]*Dr. R Satheesh (co-author): Assist Professor, Dept. of EEE, SCT, Salem, Tamil Nadu, India*

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Abstract - *An in-depth analysis of short circuits in power distribution systems for industry is presented. A power system short circuit study is performed to ensure the completeness of the equipment fault classification and to provide specifications for newly installed equipment to withstand the degree of short circuit that exists at each point in the system. Electrical systems Short circuit analysis helps ensure that personnel and equipment are protected, by establishing proper tripping ratings of the switches (breakers and fuses). If the extent of the system failure exceeds the interrupting capacity of the fault clearing device, the consequences can be severe. It can seriously threaten human life and cause personal injury, major property damage, fire, and costly downtime. In addition, the short circuit current obtained from the short circuit study is used for the relay coordination study.*

Key Words: Short circuit, Analysis, Industrial distribution system, Electrical power system study, Industry.

1. INTRODUCTION

A short circuit study is performed to determine the magnitude of the potential current flowing in the power system at different time intervals after the fault has occurred. The amplitude of the current flowing in the power system after a fault differs with time until they reach equilibrium. The behavior is due to the characteristics and dynamics of the system. During this time, a protection system is required to detect, interrupt and isolate these faults. The duty for the equipment depends on the magnitude of the current, which depends on the time since the onset of the fault. This is done for different fault types (three-phase, phase-to-phase, two-phase-earth and phase-to-earth) at different locations in the system. The information is used to select fuses, circuit breakers and switchgear sizes in addition to protective relay settings.

Even the best designed electrical systems sometimes experience short circuits resulting in abnormally high currents. Overcurrent protective devices, such as circuit breakers and fuses, must safely isolate the fault from a provided location with less damage to the circuit and equipment as well as less interference. for plant working procedures. Other system devices like cables, busbars and disconnecting switches, must be able to withstand the maximum mechanical and thermal stress caused due to the maximum short-circuit current flowing through those devices. The amperage of the short-circuit current is usually estimated by calculation, and the equipment is selected using the results of the calculation.

The current during a short circuit at any point in the system is limited by the impedance of the circuit and the source equipment or sources at the fault point. It is not directly related to the size of the load on the system.

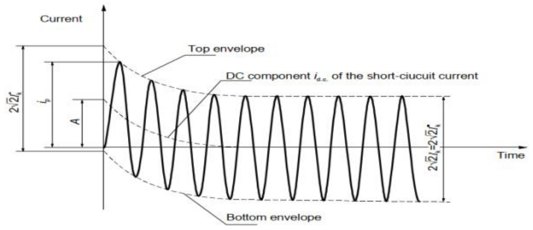
However, additions to the system to increase the ability to handle growing loads, such as a larger or larger transformer from a utility, without affecting the normal load in some locations. Existing places within the system can crucially increase the short-circuit current at these points. When an existing system is expanded or a new system is installed, the existing short-circuit current must be determined in order to apply the appropriate overcurrent protection devices.

The calculated maximum short-circuit current is almost always required. In some cases, minimum holding values are also necessary to verify the sensitivity requirements of current sensitive protective devices.

The scale and complexity of many modern industrial systems can make long-term short-circuit current calculations impractical. Calculators are often used for large short circuit studies.

1.1 Characteristics of Short-Circuit Currents

Full calculation of the short circuit currents will give the currents as a function of time at the position of the short circuit from the beginning of the short-circuit until its termination, corresponding to the instantaneous value of the voltage at the beginning time of short-circuit currents.



I_k'' = initial symmetrical short-circuit current

i_p = peak short-circuit current

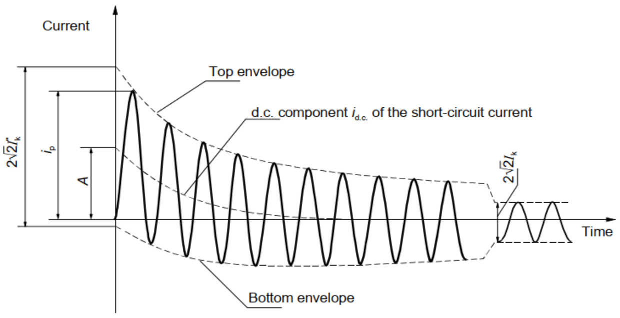
I_k = steady-state short-circuit current

$i_{d.c.}$ = d.c. component of short-circuit current

A = initial value of the d.c. component $i_{d.c.}$

Chart -1: Short-circuit current of a far-from-generator short circuit with constant a.c. component

In most practical cases, such a determination is not necessary. Based on the application of the results, it is interesting to know the symmetrical a.c. component r.m.s. value and the peak value ip of the short circuit current after the occurrence short circuit. The highest value ip depends on the time constant of the decaying aperiodic component and the frequency f, that is on the ratio R/X or X/R of the short-circuit impedance Zk, and is acheived if the short circuit begins at zero voltage. ip also depends on the reduction of the short-circuit current symmetrical a.c. component.



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$i_{d.c.}$ = d.c. component of short-circuit current

A = initial value of the d.c. component $i_{d.c}$

Chart -2: Short-circuit current of a near-to-generator short circuit with decaying a.c. component

1.2 TYPES OF FAULTS

Short-circuit faults are generally divided into symmetrical and asymmetrical types. These faults are further categorized into one of five categories. In order of frequency of occurrence, they are:

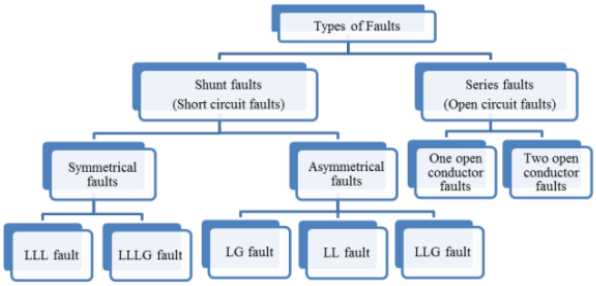

Fig-1: Different types of faults

- Symmetrical Faults:

These faults do not give rise to zero sequence or negative sequence components because they are balanced, symmetrical faults only consists positive sequence values. This is type of fault is very dangerous in the electrical system, but it is not common. This type of defect is also called as a balanced defect.

- Three-Phase Line to Line Fault: The three phase fault occurs when phases R, Y and B are shorted together but not grounded.

Fig-2: Three Phase Line to Line Fault

- Three-Phase Line to Ground Fault: The three phase to ground faults is a fault in which all the phases (R, Y and B) are short-circuited and grounded.

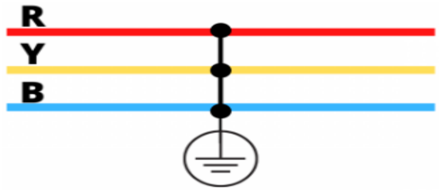

Fig-3: Three Phase Line to Ground Fault

- Asymmetrical Faults:

Asymmetrical faults require separate calculation of the positive, negative and zero sequence components separately. Asymmetrical faults are more common and less severe than symmetrical faults.

- Single Line to Ground Fault: Line to Ground fault occurs when one of the phases (R, Y or B) is grounded.

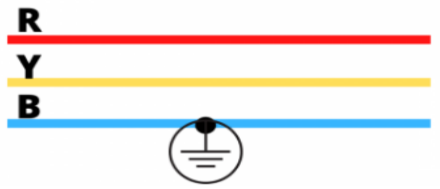

Fig-4: Single Line to Ground Fault

- Line to Line Fault: This type of fault occurs when two phases are short circuited (R-Y, Y-B or B-R).

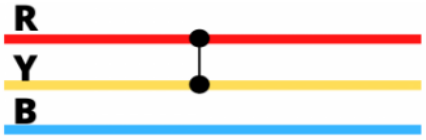

Fig-5: Line to Line Fault

- Double Line to Ground Fault: This type of fault occurs when two phases are grounded together (R-Y-G, Y-B-G or B-R-G).

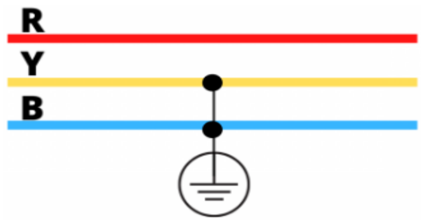

Fig-6: Double Line to Ground Fault

TABLE -1: Probability of various Short circuit faults occurrence

FREQUENCY OF OCCURENCE				
SL. NO	**TYPE OF FAULTS**	**SHORT FORM**	**SYMMETRICAL OR UNSYMMETRICAL**	**PROBABILITY OF OCCURENCE**
1.	Three phase line to ground fault	LLLG	Symmetrical	< 1%
2.	Three phase line to line fault	LLL	Symmetrical	2 – 3%
3.	Single line to ground fault	LG	Unsymmetrical	70 – 80%
4.	Line to line fault	LL	Unsymmetrical	15 – 20%
5.	Double line to Ground fault	LLG	Unsymmetrical	< 10%

1.3 SOURCES OF FAULT CURRENT

The fundamental frequency currents that flow during short circuits come from rotating machines. (Charged capacitors are capable of generating extremely high transient short circuit discharge currents, but they are equipped with a natural frequency much higher than that of the calculated power frequency. Short circuit working current does not increase appreciably by adding the discharge of the capacitor, calculated as described for RLC circuits in many electrical engineering books and the appropriate RLC circuit may be based on the electrical system data.) Rotating machinery in industrial plant short - circuit calculations may be analyzed in five categories:

- Synchronous generators
- Synchronous motors and condensers
- Induction machines
- Electric utility systems
- Adjustable speed ac induction or dc motors with solid-state ac power supply equipments

The fault current of each rotating machine source is limited by the impedance of the machine and the impedance between the machine and the short circuit. The fault current is generally not dependent of the machine's pre-fault load. The impedance of a rotating machine is not a simple value but a complex value that changes over time.

2. SCOPE AND OBJECTIVE

2.1 SCOPE

The scope of the project includes the completion of Short Circuit Studies for various case studies of Industrial electrical power distribution system.

2.2 OBJECTIVE

The objective of a short circuit study on a power system is carried out to ensure adequacy of fault rating of existing equipment and to achieve specifications of the new equipment to be installed to withstand short circuits level available at each point of the power system.

3. SHORT – CIRCUIT CURRENT CALCULATION

3.1 FUNDAMENTALS OF SHORT - CIRCUIT CURRENT CALCULATIONS

Ohm's law, I = E/Z, is the basic relationship used to determine I, the short - circuit current, where E is the source control voltage and Z is the source impedance at the short circuit point, including source impedance.

Most industrial systems have multiple short circuit supplies as each motor can contribute. One step in short-circuit current calculation is to simplify the multiple-source system, provided that the basic relation is applied.

3.2 PURPOSE OF CALCULATIONS

The complexity of the system and equipment together with the lack of precise parameters make the precise calculation of the short-circuit current extremely difficult, but extreme precision is not necessary.

The calculated maximum short-circuit current value is used to select a breaker with an appropriate short-circuit capacity, to verify the ability of power system components to withstand mechanical and thermal stress, and to determine coordination. current time of protection relay . The minimum values are used to set the required sensitivity of the protective relay. The minimum short-circuit values most of the times are estimated as fractions of the maximum values. Under this case it is enough to calculate the maximum value of the short-circuit current.

To calculate the maximum short-circuit current, the industrial electrical system should have the largest expected number of rotating machines connected (usually the system is at full load in the future).

3.3 DETAILED SHORT – CIRCUIT CURRENT CALCULATION PROCEDURE

An important part of preparing for the short circuit current calculation is setting the impedance of each circuit element and converting the impedances so that they match each other for series and parallel connection. Sources of impedance values for circuit elements are the nameplates, manuals, manufacturer's catalog, tables contained in this chapter, and contact the manufacturer directly.

Two consistent forms are established to represent impedance as ohms and per unit (each differs by a percentage by a factor of 100). The impedance of an individual device is often given as a percentage, which facilitates comparisons, but percentage impedance is rarely used without conversion in system calculations. The unit form of impedance is used because it is more practical than the ohmic form when the system contains multiple voltage levels. Impedances expressed per unit on a defined basis can be directly matched, regardless of the number of voltage levels present from source to fault. For this convenience, the base voltage at each voltage level must be tied to the turns ratio of the connected transformers.

There are four base quantities in the system of units: base apparent power in volt-amperes, base voltage, base current, and base impedance. The relationship between the base per each unit and the actual quantities is as follows:

$$\text{per} - \text{unit quantity (voltage, current, etc.} = \frac{\text{actual quantity}}{\text{base quantity}}$$

Usually, an actual value is chosen for the fundamental apparent power in volt-amperes, and the base voltage at a level is chosen to match the rated voltage of the transformer at that level. The base voltages at other levels are then established by the transformation ratios of the transformer. The base current and base impedance at each level are then obtained using standard relations. The following formulas apply to a three-phase system where the base voltage is the line voltage in volts or kilovolts and the basic apparent power is the three phase apparent power in kilovolts-ampere or megavolt-ampere:

$$\text{base current (ampheres)} = \frac{\text{base kVA (1000)}}{\sqrt{3}(\text{base V})} = \frac{\text{base kVA}}{\sqrt{3}(\text{base kV})}$$

$$= \frac{\text{base MVA } 10^6}{\sqrt{3}(\text{base V})} = \frac{\text{base MVA (1000)}}{\sqrt{3}(\text{base kV})}$$

$$\text{base impedance (ohms)} = \frac{\text{base V}}{\sqrt{3}(\text{base A})} = \frac{(\text{base V})^2}{\text{base kVA (1000)}}$$

$$= \frac{(\text{base kV})^2(1000)}{\text{base kVA}} = \frac{(\text{base kV})^2}{\text{base MVA}}$$

Impedance of individual power system elements is usually obtained in the form of a conversion to the relevant bases for calculation per unit. The impedance of a cable is usually expressed in ohms. Converting to per unit using the indicated relationships leads to the following simplified formulas, where the per-unit impedance is Z_{pu} :

$$Z_{pu} = \frac{\text{actual impedance in ohms (base MVA)}}{(\text{base kV})^2}$$

$$Z_{pu} = \frac{\text{actual impedance in ohms (base kVA)}}{(\text{base kV})^2(1000)}$$

Transformer impedance is a percentage of self-cooling transformer rating in kilovolt-amps and is converted using the following:

$$Z_{pu} = \frac{\text{percent impedance (base kVA)}}{\text{kVA rating (100)}}$$

$$= \frac{\text{percent impedance (10)(base MVA)}}{\text{kVA rating}}$$

Motor reactance can be obtained from boards that provide unit resistance above the element rating in kilovolt-amps and converted using the following:

$$X_{pu} = \frac{\text{per} - \text{unit reactance (base kVA)}}{\text{kVA rating}}$$

The procedure for calculating the short circuit current of an industrial system includes the following procedures:

- Prepare system diagrams.
- Collect and convert impedance data.
- Combine impedances.
- Calculate short-circuit current.

3.4 CALCULATION ASSUMPTIONS

The calculation of the maximum and minimum short - circuit currents is based on the following simplifications.

- During the short circuit there is no change in the type of short circuit involved, i.e., a three-phase short circuit remains three-phase and a line-to-earth short circuit remains line-to-earth during the short circuit.
- The impedance of the transformers is referred to the tap-changer in main position. This is admissible, because the impedance correction factor KT for network transformers is introduced
- Arc resistances are not taken into account
- All line capacitances and shunt admittances and nonrotating loads, except those of the zero – sequence system, are neglected

Although these assumptions are not strictly true for the electrical systems under consideration, the result of the calculation meets the objective that results are generally accepted with admissible accuracy.

3.5 VOLTAGE FACTOR (C-FACTOR)

This is the voltage correction factor (commonly known as the C-Factor). The C-Factor is used to change the device impedance and the driving point voltage. The IEC suggests calculations for minimum and maximum short-circuit currents. Selecting C-Factor for Max or Min activates the desired type of calculation. We can do calculations for just either one at any time. The C-Factors varies at the voltage levels.

TABLE - 2: VOLTAGE FACTOR C TABLE AS PER IEC-60909

Voltage C Factor		
Voltage Level	C_{max}	C_{min}
Low Voltage (<1 kV)	1.05	0.95
High Voltage (>1 kV)	1.1	1

3.6 MAXIMUM SHORT CIRCUIT CURRENTS

When calculating the maximum short - circuit current, the following conditions must be taken in account:

- The voltage factor C_{max} according to Table 2 must be considered to calculate the maximum short - circuit current
- Select the system configuration and the maximum contribution of power plants and network feeders leading to the maximum value of short-circuit current at the short-circuit location, or for an acceptable network to control the short - circuit current
- When the equivalent impedance ZQ is used to represent the external network, the minimum equivalent short-circuit impedance corresponding to the maximum contribution of the short-circuit current of the network power supplies shall be used
- Motors shall be considered
- Resistance RL of lines (overhead lines and cables) is to be considered at a temperature of 20 °C.

3.7 MINIMUM SHORT CIRCUIT CURRENTS

When calculating the minimum short-circuit currents, the following conditions must be taken in account:

- The voltage factor C_{min} for the calculation of minimum short - circuit currents shall be considered according to table 2.
- Select the system configuration and the minimum contribution of power plants and network feeders resulting in the minimum value of short-circuit current at the short-circuit location
- Motors shall be not considered
- Line Resistance R_L(overhead lines and cables, line conductors and neutral conductors) must be introduced at a higher temperatures

$$R_L = [1 + \alpha\,(\theta_e - 20°C)].\,R_{L20}$$

Where

R_{L20} is the resistance at a temperature of 20°C;

θ_e is the temperature of the conductor in degrees celsius at the end of the short circuit time;

α is a factor equal to 0.004/K, valid with sufficient accuracy for most practical applications for copper, aluminium and aluminium alloys.

4. SYSTEM DATA

4.1 SYSTEM DESCRIPTION

- Facility is receiving Grid supply from Electricity Authority through 11 kV 300 Sq.mm XLPE Cable. Cable is terminated at 11 kV ICOG panel located near plant gate by electricity board. From 11 kV ICOG Panel power is supplied to 3 Panel 11 kV Switchboard with extensible bus bar located at Main Substation HT room.

- Both Transformers T1 and T2 both are rated at 1250 kVA, 11/ 0.433 kV connected between 3 panels 11 kV Switchboard and Main LT SWBD. Main LT Switchgear with short circuit rating of 50 kA is provided with extensible bus bar both the sides.

- Five DG"s, 3 of 1010 kVA, one of 40 kVA and one of 250 kVA are connected to Main LT Switchboard. Sub Distribution Boards (SDB) located at load centres are connected to the Main LT Switchboard through cables.

- Main LT Switchboard is divided into four sections; Section-1 Section-2, Section-3 and Section-4. These sections are interconnected by Bus couplers namely Bus coupler-1, Bus Coupler-2 and Bus Coupler-3.

- Main LT Switchboard Section-1 is getting supply from Transformer T1 and DG-1. From Section-1, outgoing feeders to SDB like HVAC Panel, Utility process Panel, Fire Fighting Panel, WTP Panel, Power Panel, Process Panel, 250 kVAR Capacitor Panel-1 and UPS DB are provided.

- Main LT Switchboard Section-2 is getting supply from DG-2.

- Main LT Switchboard Section-3 is getting supply from Transformer T2 and DG-3. It is providing supply to 250 kVAR Capacitor Panel-2, Utility Panel and Main Lighting Panel.

- Main LT Switchboard Section-4 receives power from DG-4 & 5. Section 4 is providing supply to Utility Block Misc Power DB and Lighting transformer, which is further connected to Main Lighting Panel.

- Total Connected Load of plant is 2285 kW. During the summer and winter season the operating Load of plant is 1823 kW and 1660 kW, Since the summer load contribution is significantly higher it is considered for System study.

- These Sub Distribution boards are further providing supply to various Static loads and Motor Loads.

4.2 SOFTWARE FOR STUDY:

The ETAP software (is a proprietary software of Operations Technology Incorporated, California, USA) is used for Short Circuit Study. The Single Line Diagram is created in ETAP with the system data and the fault currents determined at various buses; these fault currents are used for the relay co-ordination.

4.3 SHORT CIRCUIT STUDY BASIS:

- The three phase short circuit currents and earth fault currents are calculated on the basis of source impedance, transformer impedance, generator impedance and cable positive sequence impedances, up-to the location of fault.

- The short circuit study is carried out as per IEC - 60909 standard.

- Impedance values of transformers are as per transformer name plates. As these are tested values, no negative tolerance is considered for the short circuit studies.

- 80% of the LV load is considered as motor load to calculate motor contribution.

- Method-C is adopted for carrying out short circuit study in meshed networks as recommended by IEC 60909 Part-0.

- The following are the „C" factors (Voltage Factor) considered for various system voltages. As per IEC 60909 Part-0. „C" factor accounts for variations in system voltage during operation, changing of transformer taps, sub transient behaviour of generators and motors etc.

  - ✓ H.V = 1.1
  - ✓ L.V = 1.05

4.4 SHORT CIRCUIT STUDY BASIS:

Short circuit studies are carried out for two cases either anyone of these two operating cases will be utilized under any circumstances. The following are the case studies:

- Case-1: Phase Fault Study with Grid Supply (Both transformers feeding without being paralleled and All DG's in off condition).
- Case-2: Earth Fault Study with Grid Supply (Both transformers feeding without being paralleled and All DG's in off condition).
- Case-3: Phase Fault Study with Generator Supply (Three DG's (1010 kVA) operating in parallel and Transformers in off condition).
- Case-4: Earth Fault Study with Generator Supply (Three DG‟s (1010 kVA) operating in parallel and Transformers in off condition).

TABLE - 3: MAXIMUM FAULT CURRENTS

SL NO.	FROM	MAXIMUM FAULT CURRENT (kA)
1.	11 kV Metering cubicle	1.137
2.	3 panel 11 kV HT SWBD	1.137
3.	Main LT S/b Sec-1	46.772
4.	Main LT S/b Sec-2	46.772
5.	Main LT S/b Sec-3	46.772
6.	Main LT S/b Sec-4	46.772
7.	HV AC Chiller Panel	21.384
8.	HV AC Pump Panel	6.813
9.	Substation 250 kVAR Capacitor panel - 1	31.721
10.	Utility – Process-1 Panel	6.004
11.	Fire Fighting Panel	2.905
12.	WTP Panel	5.535
13.	Admin Block Power Panel	10.403
14.	UPS I/C Panel	8.565
15.	UPS O/G Panel	0.412
16.	UPS DB	37.609
17.	Process-2 panel	14.483
18.	70 kVA Capacitor Panel	13.116
19.	Compressor Iso. panel	15.125
20.	SMD UPS 20 kVA	7.583
21.	180 kVAR Capacitor Panel	18.265
22.	Substation 250 kVAR Capacitor Panel - 2	34.716
23.	Process-3 Utility Panel	6.267
24.	Process-3 Small power panel	4.096
25.	Process-3 AHU1 Panel	2.808
26.	Process-3 AHU2 Panel	2.29
27.	Process-3 AHU3 Panel	1.876
28.	Process-3 UPS Panel	-
29.	Filter making Panel	1.155
30.	STP Panel	1.421
31.	Main Lighting Panel	19.468
32.	LP Process-2	2.961
33.	LP Process-3	3.921
34.	LP Admin block	2.654
35.	Emergency Panel	5.942
36.	Admin Incomer	0.85
37.	SMD TPDB	0.877
38.	Utility Block Misc Power Panel	13.165
39.	MCC Pump Panel	6.03
40.	Fuel Transfer Panel	3.82

5. RESULT

Short Circuit Analysis for the selected Single line diagram of over 40 bus was performed for various case studies using Etap software and the outcome has been listed for various case studies. All the equipments rating like Bus bar ratings, Circuit breaker ratings, Cable ratings, were evaluated and all the equipment was found okay to withstand maximum short circuit current(as listed in Table-III), hence these equipments can be allowed to continue their operation.

The results of short circuit studies are useful in order to determine system configuration, system voltage levels, protection equipments, switchgears, and cables size, transformers, grounding and earthing.

6. CONCLUSIONS

Short circuit current calculation was performed as per IEC – 60909. We can conclude the values of maximum short circuit current and minimum short circuit current can be utilized for the further study of Relay/ Release co-ordination studies.

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