Significance of Touch Voltage & Loop Impedance in Saudi Building Code & IEC

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Chirantan A Gupta
Saudi Basic Industries Corp.
PO Box 10040, Al-Jubail, 31961
Kingdom of Saudi Arabia

Abstract - Saudi Building Code encompassing the Saudi Electrical Code SBC 401 has now been implemented for all Industrial buildings in Stage 2 of implementation. The Code has requirement for basic protection and fault protection. Prospective touch voltage shall not persist for a time sufficient to cause a risk of harmful physiological effect in a person exposed to such live equipment. This necessitates automatic disconnection of protective device within specified time limit. SBC 401 provides the loop impedance requirement to satisfy the adequate L-G fault current. This requirement which is built around IEC 60364-4-41 statutes, needs to be revisited for LV power systems. Specific LV case studies shall be demonstrated to show complexities involved and mitigation. Identical requirements in UK IET wiring regulations (BS7671) shall also be discussed.

Index Terms — protection against electric shock, equipment grounding, fault loop impedance, maximum disconnection time, protective conductor, safety.

I. INTRODUCTION

The basic principles of protection against electric shock are well espoused in the suite of IEC standards established by IEC Technical Committee 64 Electrical installations and protection against electric shock. In Kingdom of Saudi Arabia, Saudi Building Code (SBC) has been issued by a Royal Decree and further implemented in five different stages.

SBC encompasses Saudi Electrical Code SBC-401 which has been developed based on standards of the Saudi Arabian Standards Organization (SASO) which in turn is based on IEC Standards Series of IEC 60364 (Low-voltage electrical installations). SBC-401 (referred to as Code in this article) is being implemented in separate stages from 2020 till 2023. In stage 2, implemented in 2020, all Industrial buildings were addressed by the Code. The Code provides the minimum requirements to safeguard life, health, properties and public welfare by regulating and controlling the design, installation, and use of electrical systems and equipment in the buildings at the Kingdom of Saudi Arabia.

Part 4 of the Code lays down the basic requirements of Protection against Electrical shock. Protection is provided by the design of the equipment itself, application of a measure of protection or a combination of both.

The well laid principles of protection against direct contact by means of insulation, obstacles and/or placing out of reach has been espoused. Protection against indirect contact, is ensured by automatic disconnection of power supply.

In this article we shall investigate the requirements and practical significance of automatic disconnection of power supply.

II. CODE REQUIREMENTS

A. Permissible Touch Voltage

The Code in Article 41-1.3.2.5 for systems with nominal voltage greater than 50 V a.c or 120 V d.c, has specified that disconnecting times detailed below in (B) are not required if the output voltage of the source is reduced in not more than 5 s to 50 V a,c or 120 V d.c or less. These are well established threshold values also identified in IEC 60364-4-41 Sec.411.6.2. Thus, the Code is aligned with the safety principles of IEC.

B. Maximum Disconnecting Times

The disconnecting times for TN & TT systems has been provided in Table 41-1 of the Code

Table 41.1 Maximum disconnection times

System	$50V < U_0 <=$ 120V		$120V < U_0 <=$ 230V		$230V < U_0 <=$ 400V		$U_0 > 400V$ s	
	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.	a.c.	d.c.
TN	0.8	-	0.4	5	0.2	0.4	0.1	0.1
TT	0.3	-	0.2	0.4	0.07	0.2	0.04	0.1

The maximum disconnection time indicated in above Table shall be applied to final circuits not exceeding 32A, for both TN and TT systems.

A conventional disconnecting time not exceeding 5 s is permitted for distribution circuits and circuits in excess of 32A, for TN System. In TT system, the disconnecting time is reduced to 1 s or less.

The above values are well aligned with the values provided in Sec.411.3.2.2 (Table 41.1), 411.3.2.3 & 411.3.2.4 of IEC 60364-4-41.

C. Loop Impedance

The characteristics of protective devices and the circuit impedances shall be such that, if a fault of negligible impedance occurs anywhere in the installation between a phase conductor and a protective conductor or exposed conductive part, automatic disconnection of the supply will occur within the specified time, the following condition fulfilling this requirement (Article 41-1.4.3 of the Code):

$$Z_s \times I_a <= U_0 \quad (1)$$

where

Z_s is the impedance, in ohms, of the fault loop comprising the source, the live conductor up to the point of the fault and the protective conductor between the point of the fault and the source

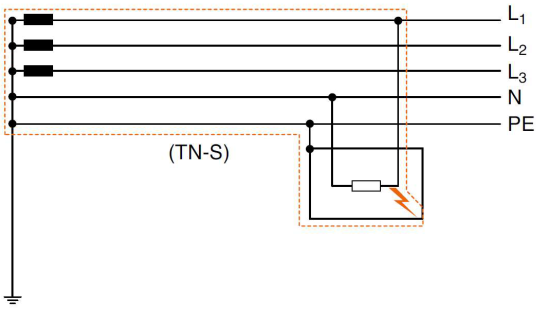
I_a is the current, in amperes, causing the automatic operation of the disconnecting protective device within the time stated in Table 41-1 as a function of the nominal voltage U_o, or under the condition stated in 41-1.3.2.3, within a conventional time not exceeding 5 s;

U_o is the nominal a.c. voltage, in volts, to earth.

III. CASE STUDIES

Various cases which involve 230V, 1 phase systems as well as 480V, 3 phase systems were studied. The practical aspects of LV power distribution were examined for adherence to the requirements of the Code.

A. 230V lighting and small power circuits (TN-S system)

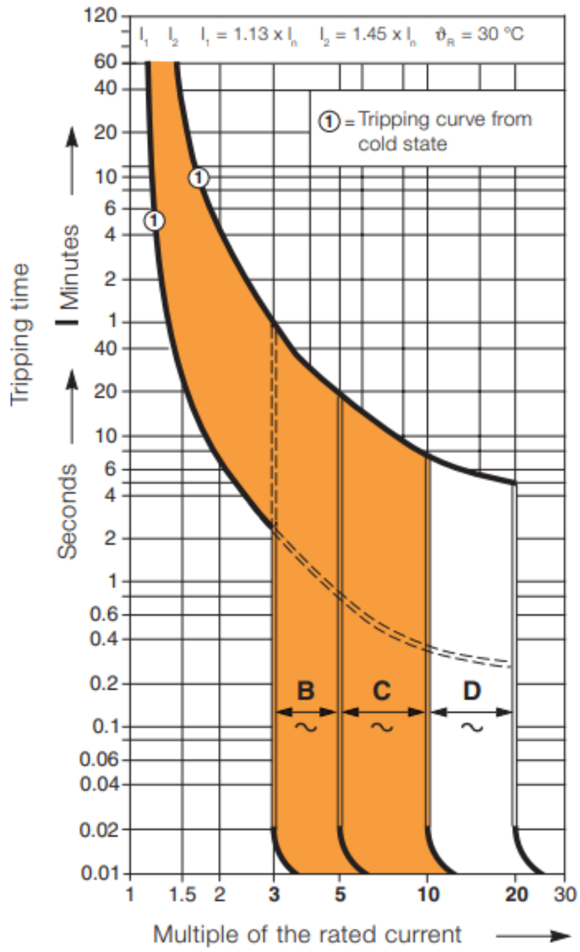


In TN-S system all exposed and extraneous-conductive-parts of the installation are connected directly to the earthed point of the power supply by protective conductors

In all buildings like Substations, warehouses, Administration building etc., we have 230V a.c, 1 phase branch circuits which need to be examined for loop impedance. Lighting circuits leaving substation for process areas also need to be properly designed. In all megaprojects and site projects, normally each individual circuit is not designed to meet voltage drop or loop impedance requirements. Instead, design is based on permissible cable length charts.

Single phase ac circuits are protected by MCBs with fixed time-current characteristics which fall under types B, C and D as defined in IEC 60898-1. It must be noted that as per IEC 60364-4-41, the maximum disconnection time for final branch circuit not exceeding 32A, is 0.4 sec.

TYPE	RANGE
B	Above 3 I_n up to including 5 I_n
C	Above 5 I_n up to including 7 I_n
D	Above 10 I_n up to including 20 I_n



The above comparison of the different types of breakers directly has a significance on the fault current that activates the breaker.

Examining the formula, $Z_s = U_o / I_a$, we can conclude that B type breaker with 5 I_n activation current (maximum value from the range is always chosen for loop impedance calculations) has the highest loop impedance while D type breaker with 20 I_n activation current has the lowest loop impedance.

Executing the permissible cable length calculations for different cable sizes and separate breaker types (B, C, D) we summarize our findings in the table below

PERMISSIBLE LENGTHS in m (2.5 sq.mm Cu cable)			
Bkr AT	B	C	D
2	1216.8	608.4	434.3
4	608.4	304.2	217.4
6	402.1	205.3	145.0
10	243.4	121.7	86.8
16	152.4	76.2	54.5
20	-	-	-
25	-	-	-
32	-	-	-

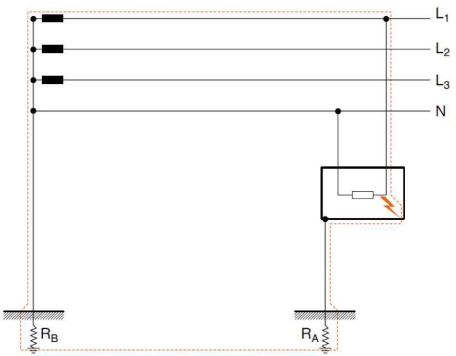
PERMISSIBLE LENGTHS in m (4 sq.mm Cu cable)			
Bkr AT	B	C	D
2	1955.3	977.7	698.0
4	977.7	488.8	349.4
6	646.1	329.9	232.9
10	391.1	195.5	139.4
16	244.8	122.4	87.6
20	195.5	97.8	69.7
25	156.4	78.2	56.1
32	-	-	-

We can see that the permissible lengths for the common cable sizes of 2.5 sq.mm and 4 sq.mm are well within the typical lengths that will be experienced in a domestic or non-industrial setup utilizing B type breakers.

However, for industrial projects, where circuit lengths can easily exceed 150 to 200m, using C and D type breakers poses a challenge especially for breakers rated 10A and above. The mitigation suggested is to employ permissible cable length charts (identical to voltage drop), to aid correct selection.

Where cable size does not mitigate the loop impedance requirement, the Code recognizes the need for RCDs.

B. 230V lighting and small power circuits (TT system)



In TT system, there is no protective earth conductor accompanying the phase conductor. In this system, all exposed-conductive-parts and extraneous-conductive-parts of the installation must be connected to a common earth electrode. The impedance of the earth fault loop therefore consists mainly in the two earth electrodes (i.e. the source and local electrodes) in series, so that the magnitude of the earth fault current is generally too small to operate overcurrent relays or fuses, and the use of a RCD is essential.

Based on current designs and design practices, we can consider a range of 1 to 5 ohms for each earth electrode in an industrial setting. Thus, with range of loop impedances of 2 to 10 ohms, we see that the fault current range is 230/2 = 115A to 230/10 = 23A. Even for a modestly sized 6A breaker Type C, we need 60A for successful tripping which is not satisfied.

For TT system, the Code in Article 41-1.5.2 recommends use of RCDs and overcurrent protective devices. Using a RCD with various settings of 10mA to 300mA, and normal protection device from 2A to 32A, the allowable maximum value of earth resistance can be presented. Here the premise is that the touch voltage of 50V will not be exceeded.

$$R_A \text{ X } I_{\Delta n} <= 50V \quad (2)$$

where

R_A is the total resistance in ohms of earth electrode and of the protective conductor of the exposed conductive parts (see note below)

$I_{\Delta n}$ is the rated residual operating current of the device

Note: The resistance of earth electrode in series with the protective conductor is many times that of the protective conductor. Hence the resistance of the protective conductor can be safely neglected

$I_{\Delta n}$ [A]	R_A [Ω]
0.01	5000
0.03	1667
0.1	500
0.3	167
0.5	100
3	17
10	5
30	2

C. 480V power circuits (TN-S system)

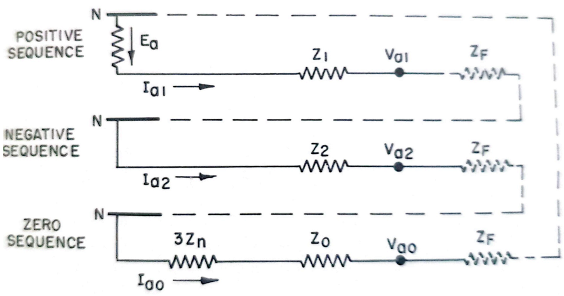
A rigorous calculation method for 480V system involves study of various possible cases in an industrial setup. It is a prerogative of the designer to examine specific cases involving long lengths of cable.

Case studies were conducted with PE conductor sized as per Chapter 54 of the Code which is based on IEC 60364-5-54 Table 54.2

Cross-sectional area of line conductor, S mm^2 Cu	Minimum cross-sectional area of the corresponding protective conductor mm^2 Cu	
	same material as line cond.	different material as line cond.
S <= 16	S	k_1/k_2 x S
16 < S <=35	16	k_1/k_2 x 16
S >= 35	S/2	k_1/k_2 x S/2

The values of k_1 and k_2 can be derived as per notes in Table 54.2.

A rigorous L-G fault calculation was executed using the basic formula derived from sequence diagram



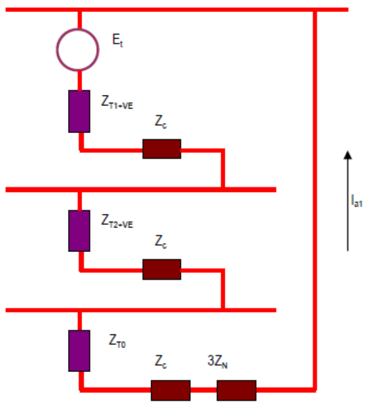
$$I_A = I_{a1} + I_{a2} + I_{a0} = \frac{3E_a}{Z_1 + Z_2 + Z_0 + 3Z_n + 3Z_F}$$

Note: The above sequence diagram and formula has been taken from Chp 2 of Industrial Power Systems Handbook – Donald Beeman [8]

It shall be noted that IEC 60909 Sec 7.5 only deals with initial line-to-earth fault current calculation with Z_1, Z_2 and Z_0. $3Z_n$ is not considered in the calculation leading to much higher L-G fault current. However, loop impedance calculation requires lower value of L-G current for it's proper investigation. Power systems software like ETAP do not calculate this L-G fault unless the relevant PE conductor sizing module is installed.

1) Case Study – 1

In this case a Cathodic protection rectifier located 250m away from 480V MCC bus was examined. The power cable was sized only on the basis of voltage drop as 4C-25 sq.mm. The supply MCCB with thermomagnetic release is sized at 70A.

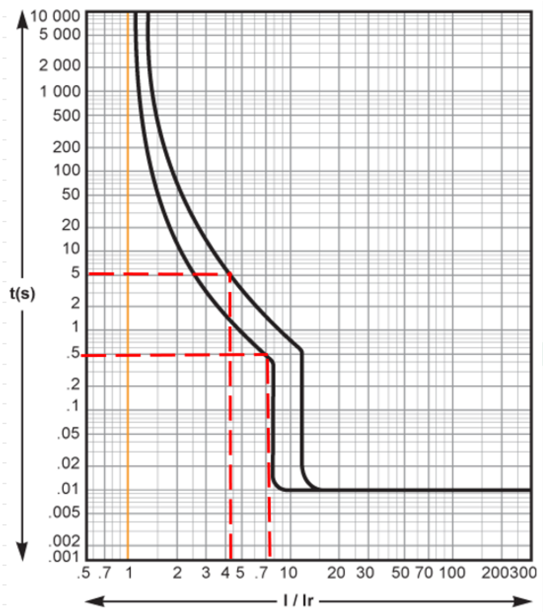


1	Base MVA	2.8	
2	Base voltage	0.48	kV
3	Base Current	3368	Amps
4	Base impedence	0.08229	ohms
5	+ve sequence current, I_{A1}	0.05460	pu
6	pu Fault Current, $3I_{A1}$	0.16381	pu
7	L-G Fault Current, I_f	551.7	A

Conclusion :

L-G Fault current for Fault at Rectifier terminals is	551.7	A
Ratio, I_f / I_n	7.88	

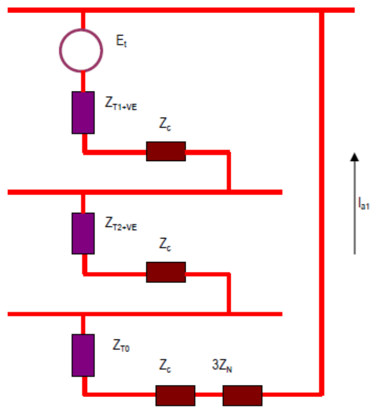
Examining the characteristics of the breaker, we see that the breaker trips at 0.5 s which is well within the 5 sec requirement as per the Code. Conversely, for 5 sec, the tripping current is 4.2 I_n i.e 294A.



Such a treatment can be executed for a particular series of breakers in a MCC to find the corresponding limiting lengths of cables. The only variables in the rigorous calculation will remain the breaker rating and the cable size & length (a particular series of breakers will have identical time-current characteristic)

2) Case Study – 2

In this case a MOV located 250m away from MCC was examined. The power cable was sized at 4C-4sq,mm. The supply MCCB with thermomagnetic release is sized at 20A.

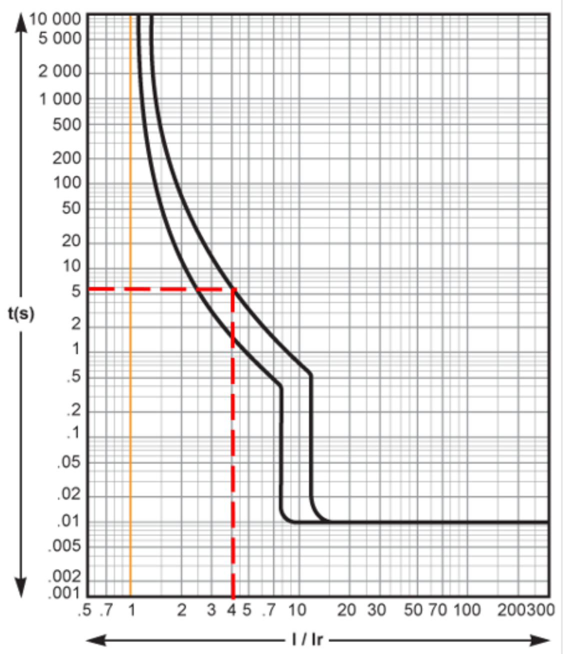


1	Base MVA	2.8	
2	Base voltage	0.48	kV
3	Base Current	3368	Amps
4	Base impedence	0.08229	ohms
5	+ve sequence current, I_{A1}	0.00868	pu
6	pu Fault Current, $3I_{A1}$	0.02604	pu
7	L-G Fault Current, I_f	87.7	A

Conclusion :

L-G Fault current for Fault at MOV terminals is	87.7	A
Ratio, I_f / I_n	4.38	

Examining the characteristics of the breaker, we see that the breaker trips at > 0.2 s which does not meet the requirement of the Code.



Here, mitigation would be to install RCD to detect and isolate earth fault.

IV. IET WIRING REGULATIONS (BS7671)

BS7671 has dealt with electrical shock protection and loop impedance in a detailed manner. It provides charts for loop impedance for compliance with 0.4 sec and 5 sec disconnection times. These are produced for breakers and fuses. For TN system, overcurrent protection device is resorted to. For TT system, RCDs are preferred with disconnection time less than one second.

V. LEGACY PLANTS

Brownfield projects and implementation of the Code requirements will be a challenge with due regard to safety. A detailed study of the Earthing system shall be conducted to ascertain the design expectations. Study of existing protection systems and any possibly retrofits are necessary.

VI. CONCLUSION

Saudi Building Code and Saudi Electrical Code SBC 401-CR implementation requires closer look at electrical shock protection requirements. These requirements are well laid out in the IEC standards and involve safe touch voltage and loop impedance considerations. Implementation of these requirements in projects at design stage is of paramount importance, for a safe and reliable installation.

VII. REFERENCES

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VIII. VITA

Chirantan A Gupta graduated from the University of Pune, India in 1992 with a BE degree, as a rank holder. He is currently working with SABIC in E&PM dept., as a Principal Electrical Engineer at Jubail, KSA. He has 30 years of experience as a lead & design engineer for various reputed firms like Bechtel, Jacobs etc. and executed pre-FEED, FEED and EPC projects. He has extensive exposure to both North American and IEC based projects and standards. He has worked in various industry segments like Oil & Gas, Power, Petrochemicals, Mining & Metals. His interests include study and analysis of low-voltage power systems and mathematical modelling. He is a registered Professional Engineer in Washington District of Columbia, and an IEEE member.
guptac@sabic.com