一分钟掌握短路电流限制

前言

电力系统中的发生短路故障是不可避免的。除了对故障点附近的破坏（例如由于电弧带来的影响），短路电流从电源流向故障点会向电缆、变压器和开关柜等设备施加较大的电动力和热应力。系统中的开关设备要能够（有选择性地）开断相关的故障电流。

然而随着发电量的增涨和系统网络互联的日益增多，以及工业用户生产规模不断的扩大，要求更大功率的设备生产，需要更大功率的变压器或新增发电机，都会导致更高的故障电流，供电系统容量的持续增涨使得系统网络达到甚至超过它们的短路电流承受能力，严重威胁用户供电系统的安全性和供电可靠性，一旦发生异常高的短路故障，断路器开关设备无法耐受并遮断短路电流，有可能导致设备损坏，甚至火灾、人员伤亡，会给用户造成非常大的损失及长时间生产中断。

如何科学有效的防治短路电流、确保供电系统安全可靠运行是电气管理者不可回避的挑战。

然而令人忧虑和担心的是，英诺威电气近年来通过走访了大量钢铁、化工、水泥、发电、石化等行业用户及工程公司设计院，经过大量调研，发现用户对于短路电流限制的理解存在诸多问题，其中最大的问题是，不少用户尚不清楚何为短路电流限制，这个最根本性的问题。

导致在短路电流限制时采取的方案出现偏差、并给系统留下严重隐患。为此英诺威基于标准和国际前沿的研究以及知名公司的素材，通过三段论的方法对何为短路电流限制加以阐释如下：

1. 短路电流限制的对象
2. 短路电流限制的定义
3. 为什么要做短路电流限制

1. 短路电流限制的对象

基于短路电流计算标准 GB/T 15544-1 中近端短路部分加以阐述

ICS 29.240.20;
F 20

中华人民共和国国家标准

GB/T 15544.1—2013/IEC 60909-0:2001
代替 GB/T 15544—1995

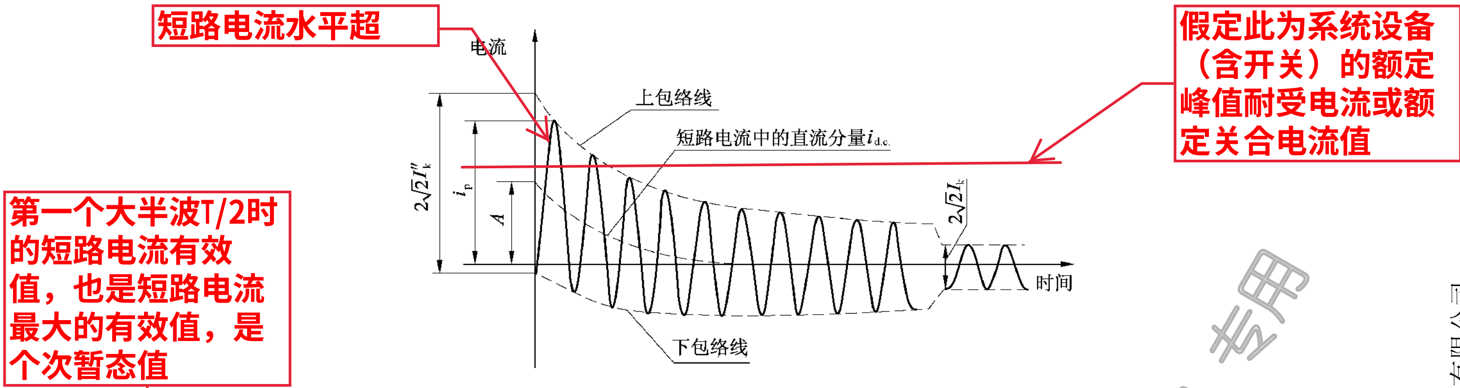
三相交流系统短路电流计算
第1部分:电流计算

**Short-circuit current calculation in three-phase a.c.systems—
Part 1: Calculation of currents**

(IEC 60909-0: 2001, Short-circuit current calculation
in three-phase a.c.systems—
Part 0: Calculation of currents, IDT)

2013-12-17 发布　　2014-08-01 实施

中华人民共和国国家质量监督检验检疫总局
中国国家标准化管理委员会　发布



说明：

I''_k ——对称短路电流初始值；

i_p ——短路电流峰值；

短路电流限制的对象

I_k ——短路电流稳态值；

$i_{d.c.}$ ——短路电流的非周期(直流)分量；

A ——非周期分量初始值。

图 2 近端短路时的短路电流示意图

实际上，绝大多情况下无需这样确定短路电流。从实际应用角度出发，特别值得注意的是短路电流对称交流分量与短路后瞬间出现的短路电流峰值 i_p 。i_p 在电压过零点短路的情况下出现，其值与频率 f 和 X/R 有关，还与交流分量的衰减有关。

在网状电网中，有若干个非周期分量衰减时间常数，因此在计算 i_p 和 $i_{d.c.}$ 时不可能给出计算精度高的简易方法。在 4.3 中，给出了 i_p 的推荐计算方法，并且具有足够的准确度。

2.2 计算假设

计算最大与最小短路电流时都应以下面条件为基础：

a) 短路类型不会随短路的持续时间而变化，即在短路期间，三相短路始终保持三相短路状态，单相接地短路始终保持单相接地短路；

b) 电网结构不随短路持续时间变化；

c) 变压器的阻抗取自分接开关处于主分接头位置时的阻抗，计算时允许采用这种假设，是因为引入了变压器的阻抗修正系数 K_T ；

d) 不计电弧的电阻；

e) 除了零序系统外，忽略所有线路电容、并联导纳、非旋转型负载。

尽管这些假定对于电力系统来讲不是严格成立，但是可以给出准确度能普遍接受的结果。

对于图 3 所示的平衡短路和不平衡短路，可用对称分量法计算其短路电流。

计算多电压等级系统的短路电流时，必须将阻抗值从一个电压等级归算至另一个电压等级下。高一级或次级电网中的设备阻抗应除以或乘以变压器额定变比 t_r 的平方，电压与电流也按照额定变比进行转换。采用标幺制时，若系统中每台变压器的变比满足 $U_{rTHV}/U_{rTLV}=U_{nHV}/U_{nLV}$ ，则没有必要进行转换，但通常情况下该条件不能满足(见 IEC/TR3 60909-2 与 IEC 60909-4 中的示例)。

2. 短路电流限制的定义

基于国际大电网会议 CIGRE 的《故障电流限制器报告》短路电流限制的定义部分加以阐述

Fault Current Limiters
Report on the Activities of CIGRE WG A3.10

by CIGRE Working Group 13.10 (*)

Abstract

A CIGRE Working Group (WG 13.10) was established in 1996 with the task to prepare a specification for fault current limiters. As a result of this work a report entitled "Functional Specification for a Fault Current Limiter" was published in 2001 [1]. The Working Group then continued its investigations on fault current limiters with a special focus on the topics "System Demands" [2], "State of the Art" [3] and "Testing" [4]. The original scope was the application of fault current limiters in distribution networks (1 kV < $U_r \leq 36$ (40.5) kV) and sub-transmission networks (52 kV $\leq U_r \leq$ 145 kV). Contributions related to fault current limiter applications in transmission networks (with U_r up to 420 kV) have however also been taken into account.

The members also undertook to assemble a bibliography on proposed solutions for the current limiting problem [1]. This showed that there has been considerable interest in the subject for almost forty years but with a few exceptions, there has been relatively little progress in developing suitable devices and bringing them to the market.

The present report gives an introduction to the problem of fault current limitation and an overview of the work carried out by the Working Group on this subject.

Keywords: Power System - Short-Circuit Current - Current Limiter

1. Fault Current Limitation

Faults in electrical power systems are inevitable. Apart from the damages in the vicinity of the fault - e.g. due to the effects of an electric arc - the fault currents flowing from the sources to the location of the fault lead to high dynamical and thermal stresses being imposed on equipment like overhead lines, cables, transformers and switchgear. The circuit-breakers further have to be capable of (selectively) interrupting the currents associated with such faults.

A growth in the generation of electrical energy and an increased interconnection of the networks lead to higher fault currents. Especially, the continuous growth in the generation of electrical energy has the consequence that networks approach or even exceed their limits with respect to the short-circuit current withstand capability. Therefore there is a considerable interest in devices which are capable of limiting fault currents. A fault current limiter can limit a fault current passing trough it within the first half cycle. The use of fault current

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limiters allows equipment to remain in service even if the prospective fault current exceeds its rated peak and short-time withstand current and in case of circuit-breakers also its rated short-circuit making and breaking current. Replacement of equipment can be avoided or at least shifted to a later date. In case of newly planned networks fault current limiters allow the use of equipment with lower ratings which renders possible considerable cost savings.

Figure 1a) shows a simple equivalent circuit for discussing the problems associated with fault current limitation in power systems [5]. Independent of the load current flowing prior to the fault, the short-circuit current starts with a certain rate-of-rise depending on the parameters of the circuit (source voltage U_0 and source impedance Z_S) and on the angle of initiation of the fault. When no limiting action takes place a fault current of shape i_1 in Figure 1b) will flow (prospective short-circuit current). This current will be interrupted by a conventional circuit-breaker at t_3.

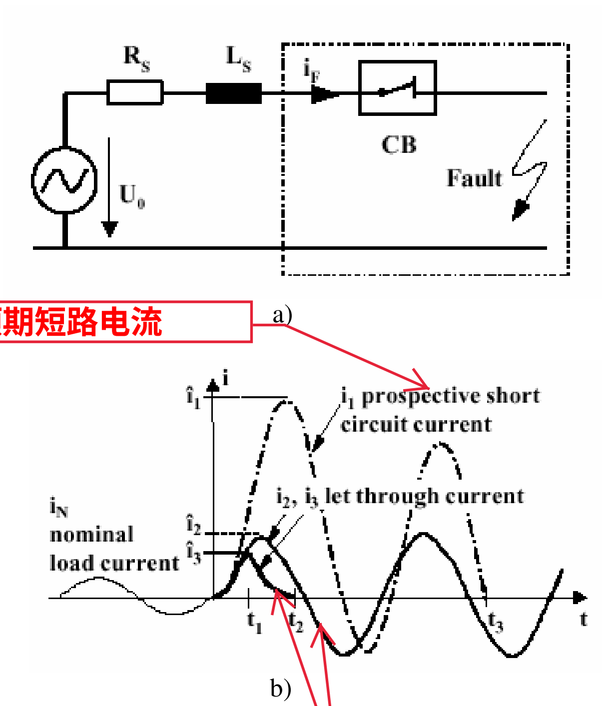


Figure 1: Fault current limitation
a) Equivalent circuit representing a fault con[...]
b) Typ[...]e to a fault

短路电流限制应实现以上两种结果：
i2, 限制不开断
i3，限制并开断

The simplest way [...]rrent would be the use of a s[...] appropriate high value. The drawback of this solution is that it obviously also influences the system during normal operation, i.e. it results in considerable voltage drops at high load currents.

In order to be able to limit the first peak $\hat{I}_1$ of the short-circuit current i_1 it is necessary for the fault current limiting device to operate within the time interval t_1 and to cause a zero or negative rate-of-rise of the current. This can be achieved by inserting a voltage or an impedance of a high enough value into the circuit. Such an action requires the use of non-linear elements and leads to currents of the shape i_2 or i_3, respectively, depending on whether the current is only limited (i_2) or limited and also interrupted (i_3). Associated with this current limitation is the generation of an overvoltage which is proportional to the superimposed di/dt.

故障电流限制器应实现的功能。

2. Description of the Limiting Behaviour of Fault Current Limiters

In the following characteristics and relations describing the limiting behaviour of fault current limiters are defined. These characteristics and relations cover the behaviour of existing fault current limiting devices (e.g. fault current limiting reactors, high-voltage current limiting fuses, I_S-limiters) as well as fault current limiting devices which are still under development (e.g. superconducting fault current limiters, solid-state fault current limiters). The following definitions apply:

Normal operation (for denominations see Figure 2):
- Peak value of rated current (I_r) - 1

Limitation (for denominations see Figure 2):
- Minimum initiating current ($\hat{I}_{min}$) - 2
- Maximum limited current ($\hat{I}_{max}$) - 3
- Peak short-circuit current ($\hat{I}_p$) - 4
- Peak value of follow current ($\hat{I}_{fol}$) - 5

有关参数定义的波形图

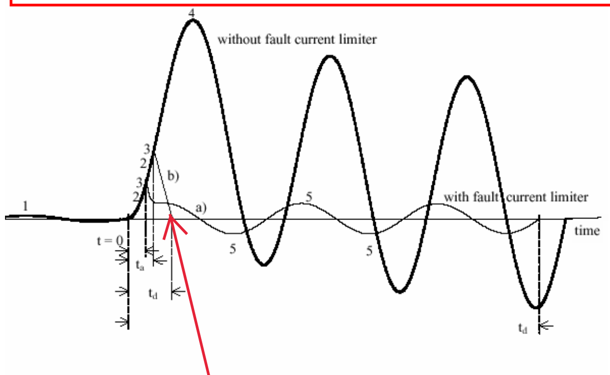


Figure 2: Definitions related to fault current limiters (see text)
a) Fault current limiting device with current limitation only
b) Fault current limiting device with current limitation and interruption

The performance characteristics of a fault current limiter can then be described using the relations given below:

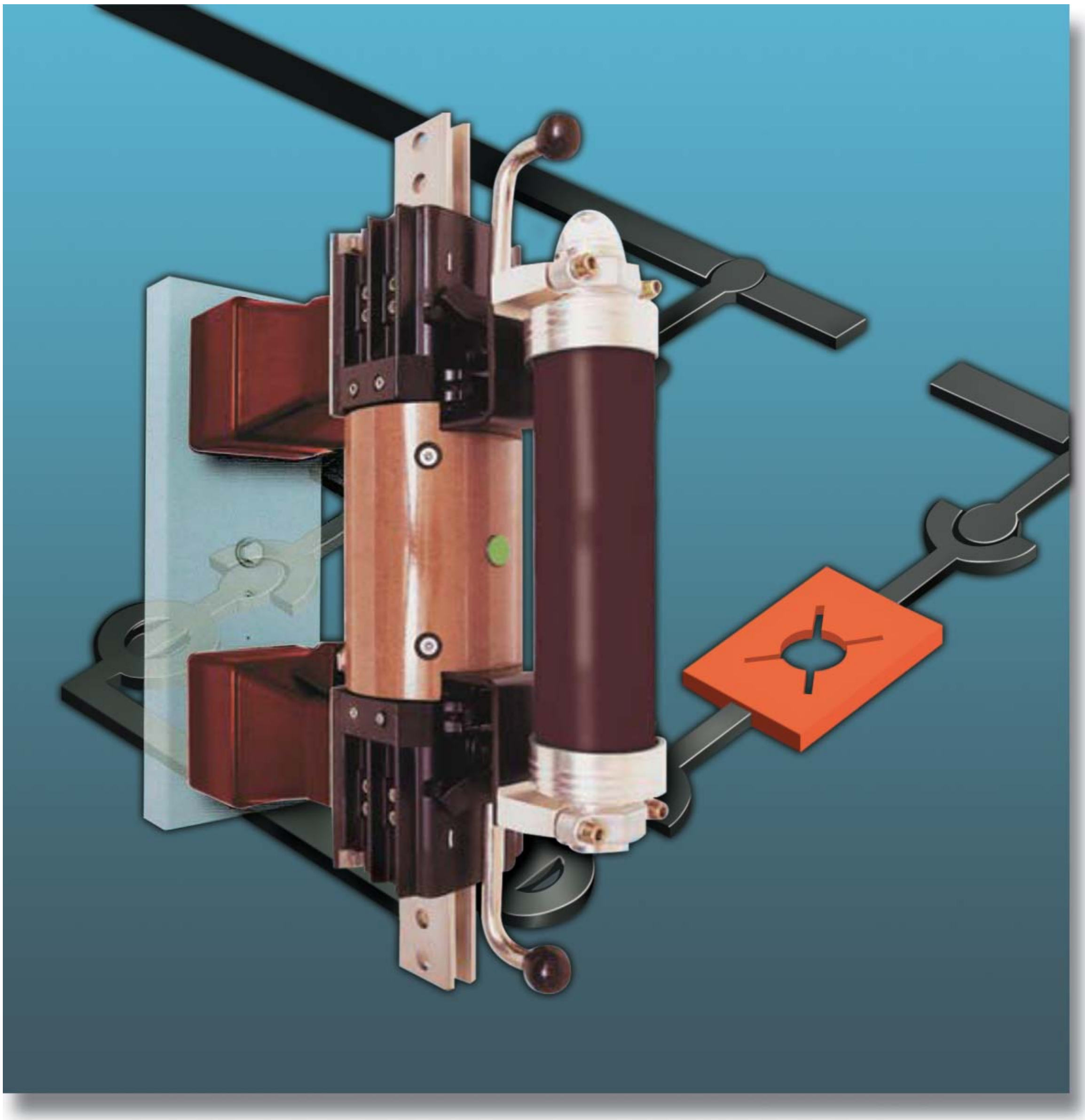
η_0: follow current ratio (ratio of peak value of the follow current (5) to the peak value of the rated current (1)), also referred to as stationary current limiting ratio η_s

火工技术限流器的限制并开断的波形为b)

3. 为什么要做短路电流限制

基于 ABB Is-快速限流器产品样本中为什么必须限制第一个大半波部分加以阐述

I_s- 快速限流器

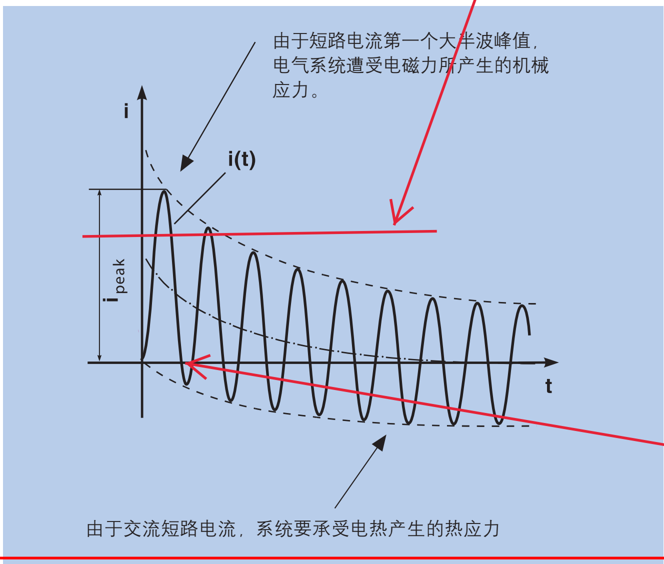


系统设备额定峰值耐受电流值，表征耐受电动力的最大能力

I_S- 快速限流器问与答

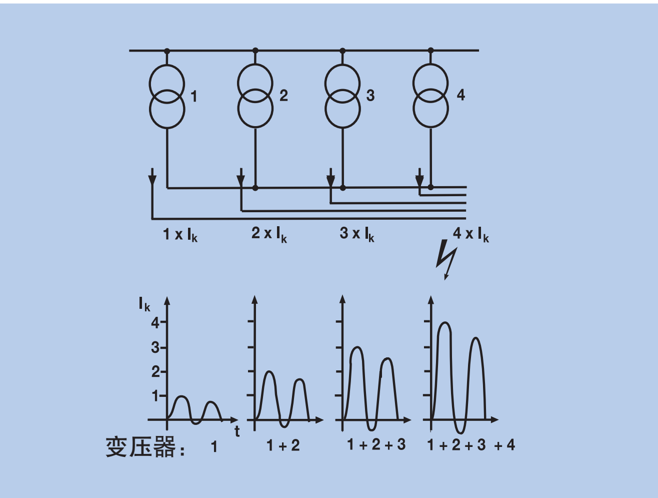
1. 什么是短路电流第一大半波峰值?

短路电流第一个大半波值 I_{peak} 是短路时，电流的最高瞬时值。



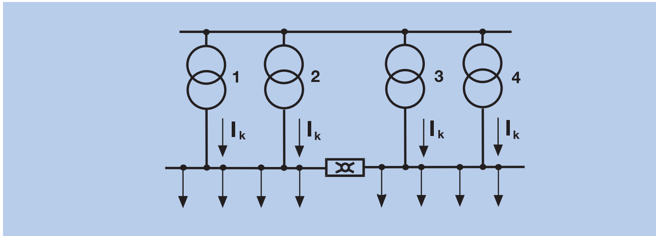
2. 为什么短路电流的峰值必需加以限制?

因为峰值短路电流将会超过开关柜、开关、电流互感器和电缆等的额定值，它们将被短路电流的电动力作用所损坏。



3. 一组只能承受 2XI_k 的开关柜，怎样配合四台变压器并列运行，而又没有过载的危险和没有额外损耗?

通过在母线 1-2 和 3-4 间加装 I_S- 快速限流器（这仅是 I_S- 快速限流器许多应用例子中的一例。其他的例子请您参见第18页）。



4 **“交流断路器并联限流电抗器的深度限流装置”首开相断路器在此时以后才能分断、投入电抗器开始限制短路电流，很明显其不能限制短路电流峰值ip（另外两相要在第二次过零或者第三次过零以后才能限流），所以“深度限流装置”并不能有效限制短路电流、保护系统。**

在正常运行时，将 I_S- 快速限流器跨接到电抗器两端将电抗器短接；严重短路时，I_S- 快速限流器动作，电抗器投入限制短路电流。