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TECHNICAL SPECIFICATION

colour inside

UHV AC transmission systems –
Part 101: Voltage regulation and insulation design

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Part 101: Voltage regulation and insulation design

FOREWORD

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Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 63042-101, which is a Technical Specification, has been prepared by IEC technical committee 122: UHV AC transmission systems.

The text of this Technical Specification is based on the following documents:

Enquiry draft	Report on voting
122/60/DTS	122/70A/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 63042 series, published under the general title *UHV AC transmission systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

Large-scale power sources including renewable energy have recently been developed. To meet the requirements for large power transmission capacity, some countries have introduced, or are considering introducing, ultra high voltage (UHV) transmission systems, overlaying these on the existing transmission systems at lower voltages such as 420 kV and 550 kV.

However, the introduction of UHV AC also presents many challenges to planners and operators. One of the major challenges is the management and control of system voltage and reactive power control. Reactive power control is normally used to address power frequency voltage requirements and maintain the voltage under transient conditions. Suitable insulation designs and coordination procedures are adopted in order to control transient overvoltages and prevent damage to equipment.

The objective of UHV AC power system design is to achieve both economic efficiency and high reliability, considering its impact on systems at lower voltages such as 420 kV and 550 kV. Long-distance transmission lines in particular generate a large amount of charging reactive power (Mvar) that could cause the system voltage to rise significantly. For example, when energizing a transmission line, the terminal voltage at the remote end could reach an unacceptable level. Reactive power compensation is implemented to ensure that the UHV AC system operates within an adequate voltage range under normal conditions and any contingency conditions that the system is designed to withstand.

Moreover, effective insulation design that limits internal electric field stress is important for minimizing and optimizing the size and structure of UHV AC transmission lines and substation apparatus. This document provides technical specifications on insulation design and coordination, reactive power compensation design and voltage regulation that are essential for maintaining UHV AC transmission systems so that they operate safely and efficiently.

UHV AC TRANSMISSION SYSTEMS –

Part 101: Voltage regulation and insulation design

1 Scope

This part of IEC 63042 specifies reactive power compensation design, voltage regulation and control, and insulation design for the coordination of UHV AC transmission systems.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60071-1, *Insulation co-ordination – Part 1: Definitions, principles and rules*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
voltage deviation
difference between the actual voltage and nominal system voltage under continuous operating conditions

3.2
network node
<in power networks> any point where two or more transmission lines meet

3.3
controllable shunt reactor
CSR
high voltage shunt reactor whose capacity can be adjusted

3.4
continuous controllable shunt reactor
CCSR
high voltage shunt reactor whose capacity can be adjusted continuously

3.5
multi-stage controllable shunt reactor
MCSR
type of controllable shunt reactor, based on the principle of high impedance transformers whose reactive power output usually varies in discrete stages and is achieved by controlling transistors, circuit-breakers and other devices

4 Reactive power compensation for UHV AC transmission systems

4.1 General principles

An appropriate amount of reactive power supply should be planned and installed in UHV AC systems to meet the system voltage regulation requirements and reduce the amount of unintended reactive power transfers between different network nodes/voltage levels.

A sufficient amount of reactive power supply with flexible capacity, including an adequate amount of reactive power reserve, should be maintained.

The capacity, type and location of reactive power compensators should be selected to improve power transmission capabilities and enhance system stability limits.

Planning and design of reactive power compensators for UHV AC systems should meet the overvoltage limit requirements for UHV AC systems.

A compensation ratio of between 90 % to 110 % is considered reasonable in planning reactive compensation to minimize the reactive power exchange between UHV and lower voltage level systems. The compensation should be judiciously implemented between line and bus reactive compensation so that it is able to control voltage during various switching operations and to prevent oscillations due to high levels of compensation.

4.2 Configuration of reactive power compensation – consider placing after general functions

In general, reactive power compensation should be distributed at the primary, secondary and tertiary side of the UHV transformer based on the overall requirements for voltage regulation and to minimize the overall cost. The principle of locating reactive power compensation at the primary and secondary sides of the UHV transformer is the same except for the cost of reactive power compensation and its effectiveness in regulating voltage at the primary side of the UHV transformer. In this way, they are treated in the same manner.

The major processes in configuring reactive power compensation for UHV AC systems are as follows:

a) Identify the range of likely active power flow across the UHV line, then calculate and analyse the characteristics of reactive power and voltage profiles along the UHV line, taking into account charging reactive power produced by UHV lines and reactive power loss under different power flow conditions. Simulations need to be repeated for each scenario to determine the compensation that keeps the voltage within acceptable limits. One of the methods for this is to determine the compensation required at each bus by using a static Var compensator (STATCOM) with a large range. The calculated output of the STATCOM that maintains bus voltage at 1,0 p.u. is the required compensation at that bus.

b) Select UHV transformer tap positions to avoid overvoltage under a range of operating conditions taking into account UHV substation location, number of transmission lines connected, and system operation mode.

c) Select capacity and location of UHV line shunt reactors with the following considerations:

   1) limiting temporary overvoltage and reducing secondary arc current;

   2) balancing charging power of lines and flexibly controlling bus voltage.

d) Identify total and unit capacity of compensators installed on the tertiary side of the transformer. Total capacity should be selected to reduce the reactive power exchange between different voltage levels and maintain bus voltage within the admissible range; the selection of single bank capacity should take into account the maintaining of voltage fluctuations induced by the switching of a single capacitor bank or reactor within a reasonable range. Set the dynamic reactive power limits provided by generators within the desired capability range.

e) Check whether the dynamic reactive power reserve provided by generators is adequate within their reactive power capability range. If it is adequate, then the process stops; otherwise return to d).

Figure 1 shows the process of configuring reactive power compensation.

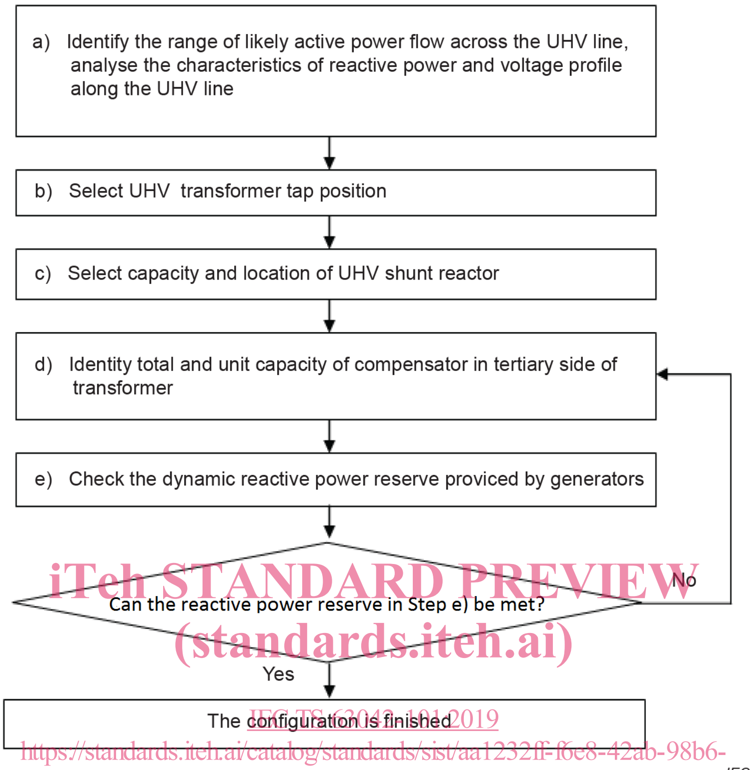

Figure 1 – Flowchart for reactive power compensation configuration

4.3 Determining reactive power compensation

4.3.1 Reactive compensation at UHV side

Reactive power compensation at the UHV side (primary side) refers to equipment that is directly connected to the UHV AC line or bus, including fixed capacity and controllable shunt reactors. UHV shunt reactive power compensation is mainly used to compensate the charging power of a UHV transmission line, limit temporary overvoltage and limit voltage to below the maximum operation voltage in transmission line energization. In addition, a shunt reactor with a neutral point reactor can be used to limit secondary arc current.

A shunt reactor connected to UHV transmission lines is used for reactive power compensation and overvoltage limiting. For substations with some short lines, the shunt reactor is normally connected to the bus, which is mainly used to compensate the charging power of the UHV transmission line.

4.3.2 Compensation at tertiary side of UHV transformers

Reactive power compensation connected at the tertiary side of UHV transformers mainly includes shunt capacitors, shunt reactors and static Var compensators (STATCOM), which are mainly used to meet the reactive power compensation requirements of the UHV AC system, to reduce the transformer‘s reactive power loss, and to regulate the system voltage.

4.3.3 Reactive power compensation at UHV side

For a shunt reactor connected to the terminal of transmission lines, its capacity can be calculated by Formula (1) below.

$$Q_{\text{HR-total}} = k_{\text{L}} \times Q_{\text{B}} \tag{1}$$

where

$Q_{\text{HR-total}}$ is the capacity of shunt reactive power compensation required at both sides of the UHV line because of this line;

Q_{B} is the no-load charging reactive power of this UHV line;

k_{L} is the compensation coefficient;

k_{L} is normally obtained based on the overvoltage calculation and reactive power balance, which is normally less than 0,85, to avoid oscillations during switching. If the line is short and line reactors are not required then the reactive power requirement can be considered in the bus reactive compensation. The requirement of a shunt reactor on the line has to be determined by the Ferranti effect during energization and temporary overvoltage studies. The nearest Mvar to the calculated value can be considered. In general, it is the compensation at each terminal of the transmission line.

For the shunt reactor connected to the bus, the capacity can be calculated by Formula (2).

$$Q_{\text{bus}} = k_{\text{B}}\left(\sum \frac{1}{2}\left(Q_{\text{B}} - Q_{\text{X}}\right) - \sum Q_{\text{HR}}\right) \tag{2}$$

where

k_{B} is the compensation coefficient, which is normally close to 100 %;

Q_{x} is the reactive power loss of the transmission line under no-load conditions, which is nearly zero;

$\sum \frac{1}{2}\left(Q_{\text{B}} - Q_{\text{X}}\right)$ is the sum of charging power and reactive power loss of half the line length of all transmission lines connected to the bus;

Q_{HR} is half of $Q_{\text{HR-total}}$.

$\sum Q_{\text{HR}}$ is the total capacity of all reactors directly connected to the UHV lines at the bus.

In general, k_{B} for the receiving end should be higher than that for the sending end. Furthermore, reactors at the generator bus and receiving end bus for light load conditions should be available. The determination of line and bus reactors as described above should be tested through simulation.