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# TECHNICAL SPECIFICATION

colour inside

## UHV AC transmission systems –
## Part 102: General system design



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

| Draft | Report on voting |
|---|---|
| 122/109/DTS | 122/114/RVDTS |

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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.

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# INTRODUCTION

Large capacity power sources including large-scale renewable energy have recently been developed, but they are generally located far away from load centres. To meet the requirements for large capacity power transmission, some countries have introduced, or are considering introducing, ultra high voltage (UHV) transmission systems, overlaying these on the existing extra high voltage (EHV) systems.

The objective of UHV AC power system planning and design is to achieve both economic efficiency and high reliability, considering its impact on EHV systems.

Moreover, UHV AC transmission systems require comparatively large spaces, and the method of minimizing and optimizing the size and structure of UHV AC transmission lines and substation apparatus is another important issue.

# UHV AC TRANSMISSION SYSTEMS –

# Part 102: General system design

## 1 Scope

This part of IEC 63042 specifies the procedure to plan and design UHV transmission projects and the items to be considered.

## 2 Normative references

There are no normative references in this document.

## 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**
**extra high voltage**
**EHV**
voltages in the range of 345 000 V to 765 000 V

**3.2**
**right-of-way**
**ROW**
strip of land that is used to construct, operate, maintain and repair transmission line facilities

**3.3**
**surge impedance loading**
**SIL**
power delivered by a line to a purely resistive load equal in value to the surge impedance of that line

**3.4**
**ultra high voltage**
**UHV**
highest voltage exceeding 800 000 V

## 4 Objective and key issues of UHV AC transmission application

### 4.1 Objective

Recently, large capacity power sources including large-scale renewable energy have been developed, in most cases, far away from the load centres. To fully utilize these facilities, it is important to transmit power generated from these sources efficiently. Evacuation through extra high voltage (EHV) network enhancements would need more lines (right-of-way, ROW) and substations, increasing transmission losses and worsening fault current problems.

UHV transmission systems are characterized by their large capacity over long distances and can provide a solution to address the above issues by minimizing ROW and switchyard requirements, effectively with fewer losses, improvement of fault current conditions, etc.

For example, the transmission surge impedance loading (SIL) capacity of a 1 100 kV transmission line can replace four to five 550 kV lines, the weight of the towers can be reduced by approximately 30 % and the weight of the wires by approximately 50 %. This can provide savings on the cost of construction of power lines and substations.

A UHV transmission system has many features such as:

- large capacity, long distance and high efficiency power transmission;
- decrease of ROW per unit GW required for transferring;
- improvement of fault current conditions and system stability;
- possible reduction of environmental impact;
- reduction of transmission losses.

### 4.2 Key application issues

UHV AC transmission systems are capable of transmitting large amounts of electric power.

However, if a failure occurs in a UHV AC system, the system influence can be severe from the viewpoints of reliability and overall security of the supply of the power system. In particular, the UHV AC transmission systems design should be considered to improve lightning and switching protection performance.



In UHV AC transmission systems, typical phenomena depend on the length of the transmission line. For the phenomenon due to the long transmission line, reactive power issues such as voltage rise due to the Ferranti effect and geometrical mean distance for increasing surge impedance loading (SIL) should be taken into consideration. For high voltage issues, it is also necessary to take into consideration secondary arc extinction, temporary over-voltage (TOV) at load shedding, and DC time constant of short-circuit currents.



In addition, size and cost of equipment are large and the system design should aim at minimizing visual impact, construction and maintenance costs and transmission losses, and increasing the network connectivity by forecasting generation and load scenarios.

The history of the development of UHV AC transmission technologies is given in Annex A.

## 5 Required studies on UHV AC system planning and design

### 5.1 General

Early strategic system planning is conducted to meet the load growth and power source development planning. Once it is determined that a new transmission line is required in the system, preliminary economic feasibility study and project design begin.

During the term of the project design, three primary decisions should be addressed in a transmission-line project at the conceptual stage: capacity, voltage, and route.

Furthermore, strategic planning, as it relates to the environmental authorizations process, is often overlooked or viewed as being of secondary importance. Early strategic planning for the project-specific environmental review process can avoid significant effects on a project's schedule, costs, and ultimate success.

### 5.2 Required studies

The analytical studies can be divided into three types, corresponding to chronological phases of a project's planning, design, and implementation:

1) System planning study

   In the planning stages, wherever new lines are needed, the voltage and current ratings, and major auxiliary equipment such as shunt compensation, are determined. At this stage, system contingencies are considered. Further studies need to be carried out for various power demand and generation scenarios, typical ones including peak demand, off peak demand for various seasons (summer, winter, rainy season), to check adequacy of the proposed transmission system. The basic study is a power flow calculation for which positive sequence parameters are adequate.

2) System impact study or detailed system design study

   The impact of new planned transmission or generation on the power system should be evaluated by the system impact study. Based on the impact study, the high-level specification shall be determined. The system impact study may result in some adjustments, or mitigations applied to the system.

   Study topics include harmonic resonance, short-circuit currents, transient stability, voltage stability, and system relaying. The study tools include short-circuit, stability, and harmonic analysis programmes, and in some cases an electromagnetic transient analytical programme to explore resonant overvoltages. The modelling needs to vary from lumped parameter to distributed parameter, from positive sequence to three-phase unbalanced representation, and from direct current to a few kHz, depending on the subject. Models are often generic in early studies, later progressing to specific models for particular equipment.



3) Equipment and system design study

   Detailed protection and operating procedures for the switchgear, shunt compensation, and related equipment are established. The basic study tool is an electromagnetic transient analytical programme.



   Accurate frequency dependent models are preferable and sometimes necessary for many of these studies.

### 5.3 Required analysis tools

The main considerations are power flow, fault current, voltage control, dynamic stability and operational criteria that include reliability and system security.

Once the high-level specification (number and type of conductors, voltage level, current rating, and reactive power compensation) has been determined, a more detailed design phase follows to specify equipment, such as circuit-breakers, shunt reactors, and surge arresters. No foreseeable problem should affect the reliable and safe operation of the system.

The analysis tool by time-domain is shown in Figure 1.

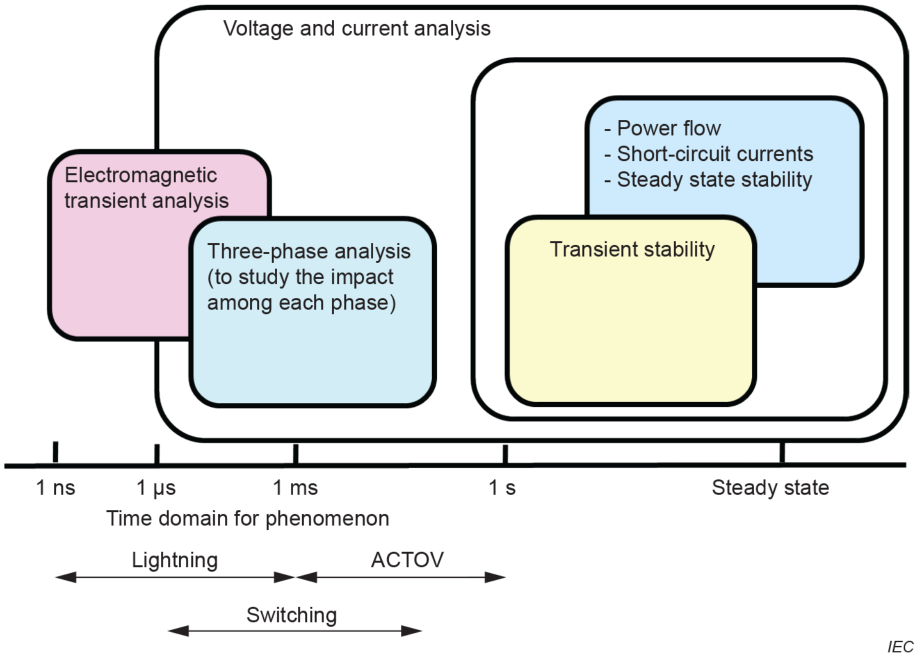


**Figure 1 – Analysis tool by time domain**

Line constants – a programme that calculates and represents electrical RLC parameters in a matrix form for a general system of tower and conductors, over a range of frequencies, and using either transposed or full unbalanced assumptions. This function may be bundled with another tool, or used separately.





Power flow – calculates steady-state voltages and currents based on a positive sequence model, with non-linear loads. The line model is symmetric and transposed. Power flow is the basic tool for transmission planning.

Short-circuit – a programme that solves voltage and current during faults, especially three-phase and single-phase-to-ground faults. The model is linear, symmetric, and assumes phase transposition. An auxiliary protection function simulates the response of relays to fault current and voltage.

Dynamics – a time-domain simulator based on numerical integration of differential equations. It differs from an electromagnetic transients programme (EMTP) as it focuses on (slower) electromechanical and control system transients, rather than electromagnetic transients. The models are sometimes linear and balanced. The programme usually includes eigenvalue analysis, or other functions for small-signal stability.

Harmonics – a frequency domain programme that solves voltage and current over a range of frequencies, using linear or non-linear load and source models, and balanced or unbalanced impedances. The frequency-scan function outputs driving point impedance, as obtained from the bus voltage for a unit current injection.

EMTP – a time-domain or transient simulator based on numerical integration of differential equations, including non-linear component models, unbalanced impedances, and frequency-dependent RLC parameters. An EMTP can also perform frequency scans, and may include an auxiliary programme of EMTP cable constants.

Electromagnetic field programme – a programme can compute electric and magnetic fields in the air and soil, as well as electric potentials, and the current distribution in the soil and in the conductors.

# 6 UHV AC system planning

## 6.1 General

### 6.1.1 Introductory remarks

Generally, the planning study process includes the following steps. As UHV AC system planning has specific requirements, some considerations are necessary for each step.

Experiences relating to UHV AC transmission development are given in Annex B.

### 6.1.2 Transmission capacity considering routes and line types to use

In the planning and design of power grid, increasing the voltage level of the transmission line to UHV not only increases the transmission capacity, but also reduces the cost of the transmission system and increases the corridor utilization rate of the transmission line.

The economic transmission distance of UHV transmission lines can be as much as 1 000 km to 1 500 km or even longer. The single line transmission capacity with 8 bundled wires can reach 12 000 MW. In the selection of UHV transmission capacity, the economic benefits of the entire power grid should be considered, rather than being limited to the economic benefits of a transmission line project.

### 6.1.3 Reactive power management issues



In the planning of the power system, the planning of reactive power supply and reactive power compensation facilities shall be included. In the engineering design of UHV AC transmission, the design of reactive power supply and reactive power compensation facilities should be carried out.



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

A sufficient amount of reactive power supply with flexible adjustable capacity, as well as reserve capacity of reactive power should be maintained.

The configuration of reactive power compensation and equipment type selection should be technically and economically compared.

Planning and design of the reactive power compensator for a UHV AC system should meet the overvoltage limiting requirement of UHV AC transmission systems.

The process of configuring reactive power compensation for a UHV AC system is as follows:

Step 1

Identify the range of likely active power flow across the UHV line, calculate and analyse the characteristics of reactive power and voltage profiles along the UHV line, taking into account the charging reactive power produced by UHV AC lines and reactive power loss under different power flows.

Step 2

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