**SLOVENSKI STANDARD**
# oSIST prEN IEC 63042-102:2020

**01-december-2020**

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**Prenosni sistemi UHV AC - Načrtovanje splošnih zahtev**

UHV AC transmission systems - General system design

**Ta slovenski standard je istoveten z: prEN IEC 63042-102:2020**

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**ICS:**

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| 29.240.01 | Omrežja za prenos in distribucijo električne energije na splošno | Power transmission and distribution networks in general |

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Other TC/SCs are requested to indicate their interest, if any, in this CDV to the secretary.

Functions concerned:
☐ EMC ☐ Environment ☐ Quality assurance ☐ Safety

☒ Submitted for CENELEC parallel voting

☐ Not submitted for CENELEC parallel voting

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The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this Committee Draft for Vote (CDV) is submitted for parallel voting.

The CENELEC members are invited to vote through the CENELEC online voting system.

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Title:
**UHV AC transmission systems – General system design**

Proposed stability date: 2024

Note from TC/SC officers:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# UHV AC TRANSMISSION SYSTEMS –

## Part 102: General system design

## FOREWORD

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IEC 63042-102 has been prepared by IEC technical committee TC122: UHV AC transmission systems.

The text of this International Standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| XX/XX/FDIS | XX/XX/RVD |

Full information on the voting for the approval of this International Standard 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.

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- withdrawn,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.

# INTRODUCTION

Large-capacity power sources including large-scale renewable energy have recently been developed, which are generally located far away from the load center. To meet the requirements for large power transmission, 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.

The objective of UHV AC power system planning/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.

Moreover, UHV AC transmission systems requires comparatively large space so that how to realize to minimize and optimize 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 63042-102 specifies the procedure to plan and design UHV transmission project and the items to be considered.

## 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 63042-101, Voltage regulation and insulation design

## 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

## 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 utilise these facilities, it is important to transmit power generation from these sources efficiently. Evacuation through Extra High Voltage (EHV) network enhancements would need more lines (Right-of-way, ROW) and substation, increasing transmission losses and worsening fault current problems.

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

For example, the transmission Surge Impedance Loading (SIL) capacity of an 1100 kV transmission line can replace 4 to 5 of 550 kV lines, effectively reducing one-third of the tower materials and one-half of the wires. It can save construction cost of the power lines and substations.

UHV transmission system has many features as follows:

- Large- capacity, long-distance and high-efficiency power transmission
- Decrease of ROW required for transferring per unit GW
- Improvement of fault current condition and system stability
- Reduction of environmental impact
- Reduction of transmission losses

Many UHV projects have been launched and are in commercial operation.

Note: Introduction of an UHV AC transmission systems can lessen or solve fault current problems in most cases, however, the effect of UHV on short circuit issues should be seen in totality.

### 4.2 Key application issues

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

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

In UHV AC transmission systems, typical phenomenon depends 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 care. For high voltage issues, secondary arc extinction, TOV (Temporary Over-Voltage) at load shedding, and DC time constant of short-circuit currents are also necessary to be considered.

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

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

### 5.1 General

Early strategic system planning is conducted to meet their 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.

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

Furthermore, strategic planning, as it relates to the environmental permitting 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/Rain), 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 has to 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 programs, and in some cases an electromagnetic transient analytical program 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 DC 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 program.

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

### 5.3 Required analyses 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 arrestors. No foreseeable problem should affect the reliable and safe operation of the system.

The analysis tool by time-domain mentioned in Figure 1.

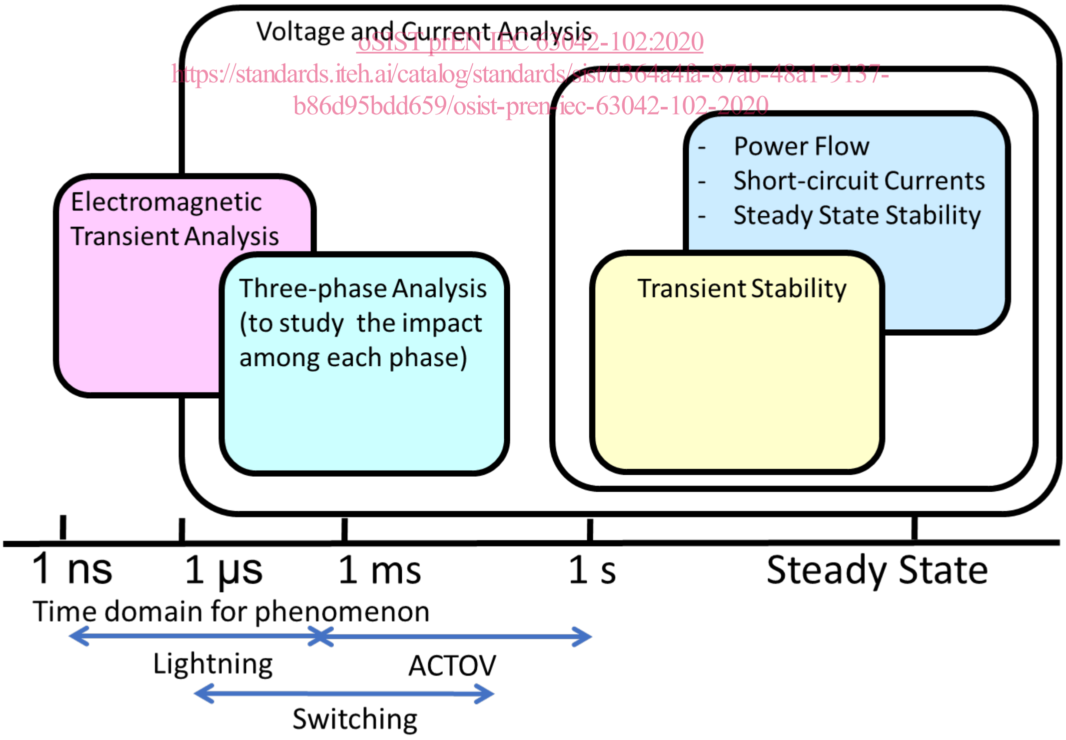

**Figure 1 Analysis tool by time domain**

Line Constants – a program 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 – calculate steady-state voltages and currents based on a positive sequence model, with nonlinear loads. The line model is symmetric and transposed. Power flow is the basic tool for transmission planning.

Short-Circuit – a program that solves for 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 Program (EMTP) in focusing on (slower) electromechanical and control system transients, rather than electromagnetic transients. The models are sometimes linear and balanced. The program usually includes eigenvalue analysis, or other functions for small-signal stability.

Harmonics – a frequency domain program 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 AUX program of EMTP Cable Constants.

Electromagnetic Field Program – A program 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

Generally, the planning study is proceeded by the following steps. As UHV AC system planning has specific requirements, some considerations are necessary in each steps.

### 6.1.1 Transmission capacity considering their 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 reach 1 000~1 500 km or even longer. The single line transmission capacity with 8 bundled wires can reach to 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.

### 6.1.2 Reactive power management issues

In the planning of the power system, the planning of reactive power supply and reactive power compensation facilities must 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.

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

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

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

1) Identify the range of likely active power flow across the UHV line, calculate and analyze the characteristics of reactive power and voltage profiles along the UHV line, taking into account of charging reactive power produced by UHV AC lines and reactive power loss under different power flows. (Step 1)
2) Select 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. (Step 2)
3) Select capacity and location of UHV shunt reactor with consideration of limiting temporary overvoltage and reducing secondary arc current, and balancing charging power of lines and flexibly controlling bus voltage. (Step 3)
4) Identify total and unit capacity of compensator installed in tertiary side of the transformer. The total capacity should be selected to reduce the reactive power exchange between different voltage levels and maintain bus voltage in an admissible range; the selection of single bank capacity should consider the voltage fluctuation induced by switching of single group capacitor or reactor within a reasonable range. (Step 4)
5) Check if 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 go back to Step 4. (Step 5)

Figure 2 shows the process of configuring reactive power compensation

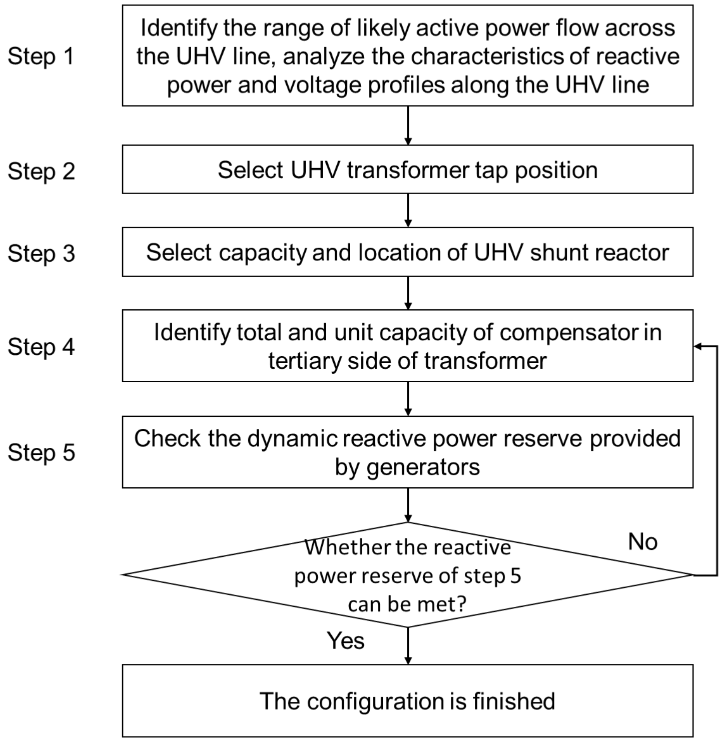

**Figure 2 The flowchart for reactive power compensation configuration**

### 6.1.3 Environmental issues

The environmental impact of power transmission project, generally includes the impact on the ecological environment, electromagnetic fields, land occupation, visual landscape, and so on. At present, the public's awareness of the quality of the environment in which they live has been strengthened, and more and more attention are paid to the environment impact of power transmission project. Related environment laws and regulations in each country should be complied with.

During the UHV AC system planning and feasibility research, environmental issues must be included. UHV AC transmission has advantages in saving the total width of transmission corridor, as a result of its huge transmission capacity. However, because of its higher voltage and rated current, it may cause more serious electromagnetic fields and related problems, which include power frequency electric field, power frequency magnetic field, corona phenomenon, radio interference, audible noise. Corresponding countermeasures should be considered during the substation and transmission line design. Appropriate test and measurement should be carried out to verify the effect of the countermeasure, during research and system commissioning.

## 6.2 Scenario planning

System planning mainly include power load forecast, power source development planning and power grid planning. System planning is formulated considering the load growth demand, site selection of power source, and paths and networking how to connect the demand side and the supply side. Then it power grid planning depends on the power development source planning. Construction of power plants requires several years but its prerequisite is that the corridors and required network enhancement is prepared.

Generally speaking, construction period of UHV transmission line may be comparatively longer than those of lower voltage level and is required more restrictions for so that it is necessary to determine when and how to introduce UHV AC transmission systems based on the accumulated experiences and findings as well as demand forecast and then formulate planning scenario to consider the required construction period and the timing of power plants commissioning.

## 6.3 Scenario procedure

### 6.3.1 Power transmission capacity

Under steady-state balanced AC conditions, a power line can be represented by the simple $\pi$ equivalent circuit shown in Figure 3.

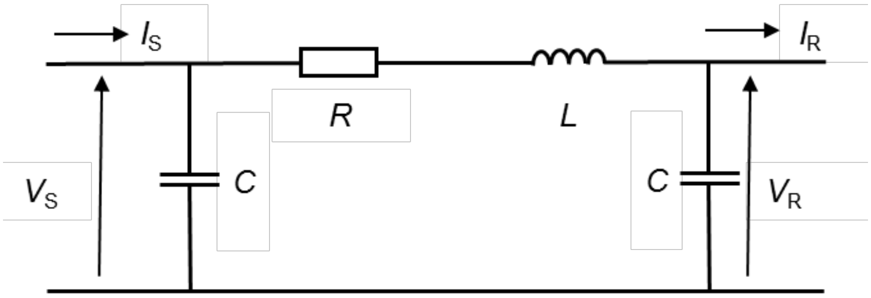

**Figure 3 $\pi$ equivalent circuit**

In Figure 3, the subscript “S” on the voltage and current applies to the sending-end and the subscript “R” to the voltage and current at the receiving-end of the line. $R$ is the series resistance, $L$ is the series inductance and $C$ is half the total shunt capacitance of the line.

Shunt conductance provides a resistive path in parallel with both shunt capacitors. However, since the basic insulation for transmission lines is air, the shunt conductance is assumed to be zero and is ignored.

An analysis of a loaded line shows that, if line losses can be regarded as small in comparison with the power transferred by the line, the maximum power that the line can transmit is given by Equation (1)

$PL= V_S V_R \sin(\delta)/X$ ……(1)

Where:

$PL$ is the power limit of the line, power transmission capacity.

$V_S$ and $V_R$ are the rms values of the sending-end and receiving-end voltages, respectively.

$X$ is the series reactance of the line.

$\delta$ is phase difference between sending end and receiving end.

### 6.3.2 System voltage

The maximum power that a line can transmit is directly proportional to the product of sending- and receiving-end voltages. Typically, in most transmission systems, sending-end and receiving-end voltages are more-or-less the same and hence the power limit is proportional to the square of the system voltage. Then higher voltages are used to increase power to be transmitted. As the voltage increases, the change in reactance is generally small. Though increases in voltage require greater phase spacing and more insulation, wider rights-of-way, or servitudes, the relationship is not linear, and the economics of line design as well as the environmental impact are, usually, in favor of increasing the voltage instead of placing additional parallel lines in the same right-of-way.

However, to upgrade the voltage, the insulation to ground and between phases has to be increased. In addition, the conductor surface gradient must to be maintained below certain levels to prevent the generation of audible noise and radio and television interference. Frequently these requirements lead to larger towers and conductors.

System voltage is described in IEC 60038 which shows 2 voltage levels (1 100 kV and 1 200 kV) so that the introduced voltage level should be selected to meet the individual network topology.

### 6.3.3 Route selection

Transmission-line routing is the selection of a corridor for a proposed line based on optimizing engineering, environmental, and economic criteria.

During the route selection process, there will be numerous tradeoffs between some factors listed previously. For example, a delta configuration tower may be desirable from an electric-field standpoint and smaller right-of-way, but taller and difficult for construction and high cost.

It is clear that each major design factor needs to be evaluated from its impact to the environment which line is to be routed. Sophisticated digital techniques, such as composite map with computer graphics, could visually indicate optimum and alternate transmission line easily. In addition, specific circumstance each area has to be considered. For example, the geographical area under consideration may have restraints concerning population density, transportation line routes, preservation of natural habitats and areas of historical significance, and the like, that could prohibit or severely restrict any transmission line construction.

There will be trade-off between environmental concerns and economics involved in line delineation. With the soaring cost of land in some areas of the country, corridor length become a crucial issue. Another factor contributing to line routing costs is the clearing method itself. If the optimum line goes through surrounding vegetation, there might be additional cost to clearing and maintenance. Also, right-of-way, such as legal fees, must be considered.

Route selection must begin early stage in the strategic of plan. This will allow optimum solution to be thoroughly documented, compared with alternatives, and presented in a convincing manner to governmental private bodies as well as to the general public.

### 6.3.4 Series compensation

The power limit is inversely proportional to the series reactance of the line. This reactance is directly related to the phase separation and the dimensions and configuration of the phase conductors as well as the line length. For a given length of line, the power limit can be increased by reducing the series reactance. This involves a reduction of phase spacing. However, considering the restriction of clearance of phase-to-phase, phase spacing couldn't be reduced much.

For long lines, it is necessary to reduce the series inductance electrically by means of series capacitive compensation.

During the project planning and feasibility research, the reactance, rated current and location should be considered.

The reactance of series capacitor is selected as a fixed percentage of the reactance of transmission line. The percentage is selected from criteria like system power flow, stability, subsynchronous resonance and so on. The cost of the equipment should be considered also. 40% series capacitive compensation degree has been used in Chinese UHV AC projects.

The rated current of series capacitor should be selected based on the research of continuous, emergency and swing current requirement of transmission line. The cost is an important issue also.

Normally, series capacitors are installed at terminals of transmission line in substations. If there is not enough space in substations, it can be installed at appropriate point of the line. However, power supply and other auxiliary equipment have to be equipped for these standalone series capacitor station.

The electrical resonance produced by the series arrangement is always below power frequency so that resonance at power and harmonic frequencies will be avoided. Series capacitor compensated transmission system connected with thermal generator, sub-synchronous resonance risk must be analyzed carefully. Accordingly after analyzing results, some specific suppression and protection technology and equipment may be necessary.

## 6.4 Required parameter

To formulate the feasible plan, the assessment by both technical and economic aspects is required so that various analyses can be carried out. In such studies, it is important to use adequate parameters so that the referential or typical parameters are prepared better in advance.

The typical required data for feasibility study are as follows.

- Line data for power flow analysis (R, X /km positive sequence)
- Line data for fault current analysis (positive sequence impedance, negative sequence impedance, zero sequence impedance/km)
- Load data
- Transformer data (e.g. reactance, impedance, grounding method)
- Generator data
- Generators' model for dynamic simulation (e.g. governor model, generator model)
- Unit price of the transmission line and substation