

TECHNICAL SPECIFICATION



**Power system stability control –
Part 1: Guideline for framework design of power system stability control**

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**Power system stability control –
Part 1: Guideline for framework design of power system stability control**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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POWER SYSTEM STABILITY CONTROL –

Part 1: Guideline for framework design of power system stability control

FOREWORD

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IEC TS 63384-1 has been prepared by subcommittee 8C, Network management in interconnected electric power systems, of IEC technical committee 8: System aspects of electrical energy supply. It is a Technical Specification.

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

Draft	Report on voting
8C/47/DTS	8C/61/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/publications.

A list of all parts in the IEC 63384 series, published under the general title *Power system stability control*, can be found on the IEC website.

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POWER SYSTEM STABILITY CONTROL –

Part 1: Guideline for framework design of power system stability control

1 Scope

This part of IEC 63384 provides guidance for power system stability control framework design. It covers the uniform use of terms and definitions, general objectives and principles for power system stability control, the classification of power system stability control, and the framework combining several types of stability controls in a coordinated and cost-effective (risk-based) manner.

In accordance with this guideline, the framework is designed to cope with disturbances of different probabilities of occurrence and impact on power system security and stability. Effective control approaches are designed to prevent or minimize the scope of future blackouts.

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 terminology databases for use in standardization at the following addresses:

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

3.1

power system stability control

<electric power system> control in a power system which prevents system insecurity, instability and collapse caused by disturbances and minimizes further loss of power supply

Note 1 to entry: Remedial Action Scheme, System Integrity Protection Schemes (SIPS), Special Protection System and System Protection Scheme are typical examples of stability control implementation.

3.2

power system stability control framework

<electric power system> framework designed to describe the fundamental principles of power system stability control, composed of a contingency list, the objective of control, the types of stability control, methods of control decision planning and control activation

Note 1 to entry: Usually, several types of stability control are combined to prevent system insecurity, instability, collapse, and blackouts upon occurrence of contingencies, so that the adaptability of each type of stability control can be enhanced and the coordination of different types of stability controls can be facilitated.

3.3

normal state

<electric power system> state wherein all system variables are within the normal range and no equipment is overloaded, and power system operates in a secure manner and is able to withstand predefined contingencies without violating any of the constraints

3.4**alert state**

<electric power system> state wherein all system variables are within the normal range and no equipment is overloaded, and power system is unable to enter into its normal state if predefined contingencies occur without control actions

3.5**emergency state**

<electric power system> stable state in which some system components are stressed beyond their ratings, or some bus voltages or system frequency are outside tolerances

[SOURCE: IEC 60050-692:2017, 692-02-06]

3.6**blackout state**

<electric power system> state where the transmission system contains areas of almost no voltage as the consequence of the tripping of generation units, transmission equipment, or both

3.7**restorative state**

<electric power system> state in which actions are performed to re-establish a normal state after the blackout state or the emergency state

3.8**contingency**

<electric power system> event that usually involves the loss of one or more components, which affects the electric power system at least momentarily

3.9**contingency list**

<electric power system> list of contingencies to be considered in order to test the compliance with the operational security limits

3.10**predefined contingency**

<electric power system> contingency to be predefined in order to test the compliance with the operational security limits

3.11**normal type of contingency**

<electric power system> contingency that incurs low risk to the secure and stable operation of the power system

3.12**exceptional type of contingency**

<electric power system> contingency that incurs medium risk to the secure and stable operation of the power system

3.13**extreme type of contingency**

<electric power system> contingency that incurs high risk to the secure and stable operation of the power system

3.14**risk**

<electric power system> combination of the probability of occurrence of harm and the severity of that harm

Note 1 to entry: Risk can consider the probability of contingency occurrence and its impact on power system security and stability. Risk may be assessed by considering the probability of implementing stability control and its cost due to the contingency (if the impact of the contingency cannot be quantified).

[SOURCE: ISO/IEC Guide 51:2014, 3.9, modified – The Note to entry is different]

3.15**compliance**

<electric power system stability control> conformity level of stability control schemes in respect of the requirements of national energy/electricity law and regulations

3.16**dependability**

<electric power system stability control> ability to perform timely stability control actions and to prevent unintended stability control action

3.17**accuracy**

<electric power system stability control> ability to implement the stability control action precisely at the right time with the right control amount and the correct control command

3.18**adaptability**

<electric power system stability control> ability to carry out appropriate control actions considering the operating condition, the contingencies, the available control resources and the control objectives

Note 1 to entry: The control decision set should be adjusted to the current operating condition and the contingencies occurred. The available control resources should also be correctly identified.

3.19**coordination**

<electric power system stability control> ability to fully explore characteristics of each type of stability control scheme for control decision planning

Note 1 to entry: Multiple automatic control schemes implemented in a region should be coordinated to avoid undesirable control actions.

3.20**rapidness**

<electric power system stability control> ability to implement control actions as fast as needed, so the power system can satisfactorily recover from the ongoing disturbance

3.21**economy**

<electric power system stability control> cost-effectiveness of stability control, meaning a balance between technical performance and economic cost

3.22

preventive control

<electric power system stability control> type of stability control, which is implemented before the occurrence of disturbances in order to prevent a power system from exhibiting a dynamically insecure behaviour if one of the predefined contingency scenarios would actually occur

Note 1 to entry: Preventive control is normally invoked by system operators, while automatic activation is permitted as well.

Note 2 to entry: Typical preventive control actions include generation re-dispatching, system reconfiguration, tap changer setpoint adjustment, high voltage direct current (HVDC) power change, shunt reactor/capacitor tripping or closing, etc.

3.23

event-based control

<electric power system stability control> type of stability control, which is immediately and automatically triggered by one of the predefined contingencies in order to prevent system instability or limit violation of key operating parameters

Note 1 to entry: Typical event-based control actions include generation tripping, load shedding, HVDC fast power running-up or running-back, shunt reactor/capacitor tripping or closing, etc.

3.24

response-based control

<electric power system stability control> type of stability control which is automatically triggered after violation of key operating parameter limits

Note 1 to entry: Triggering is achieved by comparing real-time measurements with predetermined conditions of power system responses (the disturbance-related changes in critical electrical and/or physical variables) to prevent system instability and system collapse.

Note 2 to entry: Typical response-based controls include out-of-step system separation, over-frequency generator tripping, over-voltage generator tripping, under-frequency load shedding, under-voltage load shedding, etc.

3.25

restorative control

<electric power system stability control> control actions performed to re-establish a normal state after the blackout state or the emergency state

Note 1 to entry: Restorative control takes actions to reconnect the facilities and restore system load as fast as possible in a safe manner after widespread loss of load and possibly in a scenario having islanded systems. Its objective is to minimize further loss of power supply.

Note 2 to entry: Typical restorative control actions include black start, grid reconnection of tripped equipment, start-up of reserved equipment, generation and/or transmission adequacy restoration, etc.

3.26

control decision planning

<electric power system stability control> process of identifying stability control decisions in advance, based on the analysis of steady state conditions and time-domain simulations for a set of predefined contingency scenarios

Note 1 to entry: Generally, for disturbances, control decisions shall be specified before implementing any specific control action.

Note 2 to entry: Control decisions are the control quantity, action sequences and threshold and/or setting values, etc. indexed by system operating conditions, predefined contingency scenarios or conditions (critical electrical variables, predetermined conditions of power system responses) for triggering a control action.

4 Classification of system states

4.1 General

The system operating conditions can be classified into system states, i.e., normal state, alert state, emergency state, blackout state, and restorative state.

4.2 The characteristics of normal state

The power system is in normal state when all the following aspects meet the operational security requirements:

- a) voltage and power flows;
- b) the steady state system frequency deviation;
- c) active and reactive power reserves;
- d) steady-state stability reserve;
- e) the operation of the control area is and will remain within the operational security limits after the activation of automatic stability control actions following the occurrence of a contingency from the predefined contingency list.

4.3 The characteristics of alert state

The power system is in alert state if one of the following aspects does not meet the operational security requirements:

- a) voltage and power flows;
- b) the steady state system frequency deviation;
- c) at least one contingency from the predefined contingency list leads to a violation of the requirements of operational security, even after the activation of automatic stability control actions.

4.4 The characteristics of emergency state

The power system is in emergency state if at least one of the following conditions occurs:

- a) there is at least one violation of the operational security requirements for the voltage and the power flows of the network;
- b) one of the individual variables that demonstrates the overall system state violates admissible operational limits;
- c) system instability.

4.5 The characteristics of blackout state

The power system is in blackout state if any area of the transmission system is characterized by almost total absence of voltage as the consequence of the tripping of generation units, transmission equipment, or both.

4.6 Restorative state

To recover from emergency or blackout state, the power system enters into restorative state by activating measures of restoration plan.

5 Contingency list and contingency analysis

5.1 Contingency list

A contingency list shall be established based on the risk assessment. A contingency list shall include the internal contingencies of a control area and should include the contingencies of neighbouring systems with significant impact on the control area.

Considering the probability of contingency occurrence and its impact on power system security and stability, the contingencies included on the contingency list can be classified into several types based on the result of risk assessment, such as normal type of contingency, exceptional type of contingency and extreme type of contingency. Risk may also be assessed by considering the probability of implementing stability control and its cost due to the contingency (if the impact of the contingency cannot be quantified).

5.2 Contingency analysis

Contingency analysis shall explore the possible phenomena in a power system caused by the operation of the contingency and its consequences. Contingency analysis shall be performed to identify the stability control actions that are necessary to address the contingencies.

6 Objective and general requirements of control for power system stability

6.1 Objective

The general objective of control for electrical power system stability is to maintain synchronous operation and security of power supply in the presence of disturbances. Furthermore, the stability control system can also be used to increase the transmission capacity. The safety of the primary equipment, the quality of supplied power, and costs and benefits of controls, are factors to be considered for achieving the objective of control.

The determination of the stability control objective concerning contingencies shall be based on the risk assessment by considering the probability of implementing stability control and its cost.

For the normal type of contingency and the exceptional type of contingency, the objective of the corresponding stability control is to prevent the system from entering into emergency state. For the extreme type of contingency, the objective of the corresponding stability control is to prevent a total system collapse (blackout state).

When the risk assessment results indicate that the risks associated with applying stability controls for preventing the system under some of the normal contingencies from entering into alert state are acceptable, preventing the system from entering into alert state can be used as the objective of stability control for these contingencies.

When the risk assessment results indicate that the risks associated with applying stability controls for preventing the system under some of the exceptional contingencies from entering into alert state are acceptable, preventing the system from entering into alert state can be used as the objective of stability control for these contingencies.

When the system is in the restorative state, the restorative control aims to minimize downtime and to reduce costs of the power utility and its customers.

6.2 General requirements

The design of the stability control shall consider the requirements of the following aspects: regulatory compliance, dependability, accuracy, adaptability, rapidness, coordination, economy, and risk.

7 Classification of stability control type

The classifications of power system stability control shall consider the control mechanism, as well as the typical timing and the system state condition at the time of control activation and their interaction with each other. By following this criterion, the following four control types are classified as: preventive control, event-based control, response-based control and restorative control.

8 Control decision planning

8.1 General

Within the design period for stability control, the possible scenarios of power system operation shall be taken into account. The adaptability of each type of stability control should be ensured. The coordination of different types of stability controls shall be based on risk assessment. The control decisions for all the contingencies on the contingency list shall be coordinated to achieve a system-wide optimal solution.

8.2 The stability control types applied for the contingency list

To determine the stability control types applied for the contingency list, the following aspects shall be considered:

- the possible power system phenomena under the contingency;
- the objective of stability control for the contingency list;
- the features of each individual stability control type;
- the requirements of technology application and engineering implementation;
- the cost-benefit analysis.

Multiple types of stability control shall be considered to achieve the objective of overall system stability control. The determination of the stability control types for the contingency list shall be based on risk assessment.

By means of risk assessment, one or more types of stability control, together with their optimal coordination scheme, can be adopted. Following the result of risk assessment, some typical examples are as follows.

- a) When the level of risk associated with a normal type of contingency, handled by appropriate preventive control, is less than by any other controls in combination, then the preventive control alone can be used to address these contingencies for maintaining operational security.
- b) When the level of risk associated with a normal or exceptional type of contingency, handled by an appropriate event-based control, is less than by any other controls in combination, then the event-based control alone can be used to address this contingency for maintaining operational security.
- c) When the level of risk associated with an extreme type of contingency, handled by appropriate response-based control, is less than by any other controls in combination, then the response-based control alone can be used to minimize the impact of the contingency, i.e. to prevent a total system collapse (blackout state).

8.3 The method of control decision planning

Control decisions shall be analysed and specified before implementing any specific control action.

Both the static and dynamic characteristics of the power system shall be considered when planning the control decision.

Control decisions shall be determined by utilizing steady state and time-domain analysis under predefined contingency scenarios. The dynamic models shall be required for all dynamic devices in a power system, such as automatic voltage regulators (AVR), power system stabilizers (PSS), governors, HVDC, flexible AC transmission systems (FACTS), and renewable energy sources (RES). The operational state of all dynamic devices in a power system shall be in accordance with their actual situations. The degree of details in system modelling and simulation for planning control decisions shall consider the nature of the stability problems in question.

The planning of control decisions of multiple types of stability controls in combination shall be based on risk assessment.

It shall be ensured that planned decisions can be practically implemented. It shall be ensured that the planned decisions account for the complexity of the phenomena, the expected time of activation, and the urgency of the system operation situation that control decisions intend to resolve.

8.4 Approach for enhancing the adaptability of stability control

To enhance stability control adaptability, the period of control decision planning can be reduced. For example, a system of online analysis and planning of control decisions can be used. This is appropriate if power system operational conditions can be evaluated by state estimation in near-to-real-time and a system model representing both the static and dynamic characteristics of the power system is available.

To ensure the adaptability of stability control caused by the changing system condition, the control decision shall be re-planned if there have been significant changes in the power system. These changes are usually topology changes, active and reactive power flow changes, active or reactive power changes on power generating units and large amount load switching on/off, etc. For example, when forecasted or typical conditions are used in offline planning approach, there is an associated uncertainty in the control decisions caused by changing the system conditions. Improved control decisions will be achieved if the online planning approach can be used, which is based on a snapshot of the actual system condition.

The control decision shall be re-planned whenever the stability control system conditions are changed, such as their availability, the time and resources needed for their activation.

When the operating condition is validated and updated, the verification of planned decisions should be employed, so that the effectiveness of control decisions can be achieved.

In order to enhance the event-based control adaptability, the event-based control systems shall be capable of receiving and updating the online planned decisions which are based on the online planning of control decisions.

If the typical restorative plans have been prepared, they may be further optimised in online setting by referring to the planned restorative plan after a blackout state occurs.

8.5 Approach for enhancing control decision coordination

The characteristics of each type of stability control shall be fully explored for control decision planning. The coordination of multiple types of stability control shall be based on risk assessment.

Preventive control decision planning shall be conducted by considering adequacy and the coordinated performance of existing controls, including event-based control and response-based control. This should be done under system operating conditions and predefined contingency scenarios or conditions.

9 Framework of stability control

The general framework of stability control is shown in Figure 1.

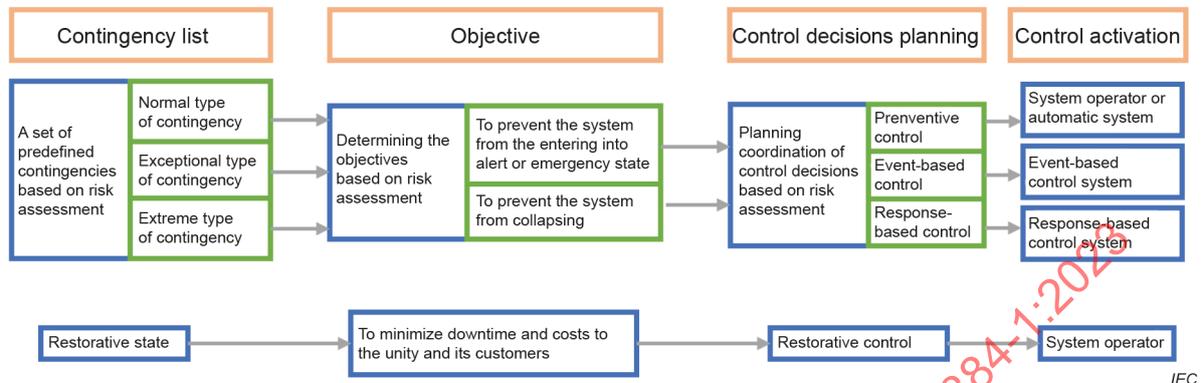


Figure 1 – The general framework of stability control

10 Considerations in the implementation of stability control schemes

10.1 General

In the implementation process of stability control schemes, a system study shall be required. Coordination with other protection and control systems, the impact of neighbouring systems on stability control, the communication system and cyber-security shall be considered.

10.2 System study

The purposes of system study should include the following:

- Explore the possible power system phenomena under pre-defined contingencies. It should be noticed that multiple types of phenomena can occur concurrently as the result of a severe disturbance.
- Identify the contingency involving power system instability if no control measures are employed, determine the effects of contingency on system performance, and determine the extent of a widespread system disturbance.
- Determine the most appropriate type of stability control action and implementation schemes.
- Consider the technical performance requirements of the control measures if they are required.

The system study should consider the following aspects:

- the power system structure and composition of different types of power generation;
- the problems and phenomena of power system instability and insecurity including, but not limited to:
 - 1) rotor angle instability;
 - 2) frequency instability;
 - 3) voltage instability;
 - 4) resonance instability;
 - 5) converter-driven instability;
 - 6) key parameter limits violation;

- the performance requirements and rules of power system operation, including but not limited to:
 - 1) whether the interruption of a transmission service by a utility company is allowed and whether non-consequential load loss is allowed, in the case a specific type of contingency occurring;
 - 2) the permissible range of variation in voltage and frequency and permitted duration time of a variation with respect to power system operation in normal state, alert state, emergency state and restorative state;
 - 3) the permissible range of system operation performance parameters, such as the damping ratio and the short circuit ratio.

The system study should consider both the typical operating condition and the contingency scenario. The setting of the base case should cover all the planned steady-state system conditions, and accommodate various factors such as load level, changes to network topology, and composition of different types of generation.

10.3 Coordination with other protection and control systems

The design basis and planned control decisions of stability control should be reviewed and coordinated with other protection and control systems, and control resetting should be made whenever necessary to ensure coordination of automatic control operations for the planned system conditions.

10.4 Impact of neighbouring systems on stability control

During the process of design, neighbouring systems should be considered. The neighbouring systems include external electrical networks and grids of lower voltage level if necessary.

10.5 Communication system and cyber-security

A secure communications system shall be provided to ensure that event-based control system and response-based control system/devices deliver the required data.

The assessment of communication system should include performance, reliability and security.

Cyber-security countermeasures should include cyber-attack detection and cyber defence. New types of contingencies to account for cyber-attacks should be taken into consideration.