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1.1 POWER PLANT COMPLIANCE TESTS WITH GRID CONNECTION REQUIREMENTS

1.1.1 Introduction

In nowadays power systems, new power plants that use different electricity generation technologies are built more often than in the last decades. Therefore, it is very important to know precisely the requirements related to the compliance tests that should finally lead to operational notification of a power plant issued by the relevant transmission system operator (TSO). Firstly, the set of requirements for compliance tests provides the technical requirements for grid connection and point to the needed technical documentation. When technical documentation is prepared properly and the compliance tests are performed successfully, the final operational notification is issued by TSO.

The legal framework for compliance tests is: Commission Regulation (EU) 2016/631 of 14 April 2016: "Establishing a Network Code on Requirements for Grid Connection of Generators", THE EUROPEAN COMMISSION, abbreviated RfG, which full implementation in the European Union started on April 27, 2019. According to RfG power-generating modules are divided into groups with a pre-known set of requirements. The groups are formed in relation to electricity generation technology, and maximum capacity and the voltage level at the connection point.

The content presented in this course topic is partly based on the study authored by V. Kostić et al., "Proposal of Compliance Tests Protocols for Power Generation Plant with Technical Requirements for its Connection to Distribution System". This study was ordered by Utility of Serbia and done by University of Niš - Faculty of Electronic Engineering (UNI-FEE), Serbia, in 2021. Subject of the study was the harmonization of the existing Distribution Network Code with RfG, in the part related to the compliance tests for power-generating modules. The aim of the study was to provide: the proposal of requirements for compliance tests for different types of power-generating modules, and the proposal of protocol for each specific compliance test.

In this course topic very important matter is presented for both industry and academia. Facility owners should be aware and very well informed in details about requirements for compliance tests. This is of crucial importance for them from a technical and economic point of view, since the design and building of the power plant is not economically justified if plant operational notification will not be issued. On the other hand, the students of electrical power engineering should study about grid connection requirements and compliance tests that have to be performed in today's power systems. This study covers: division of power-generation modules, requirements for compliance tests for different types of power-generation modules, and compliance tests and operational notifications for all types of the modules.

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1.1.2 Division of power-generating modules

Since power-generating modules can have different characteristics, the idea applied in RfG is to divide power-generating modules into groups, and each module that belongs to one group has a set of requirements related to compliance tests, known in advance. For division of power-generating modules into groups the following information about each power-generating module is a prerequisite:

- electricity generation technology,
- maximum capacity and the voltage level at the connection point.

1.1.2.1 Electricity generation technology

In turms of electricity generation technology power-generating modules are divided to:

- synchronous power-generating modules, and
- power park modules.

In the case of synchronous power-generating module frequency of the generated voltage, the generator speed and the frequency of network voltage are in a constant ratio and thus in synchronism. On the other hand, power park module is non-synchronously connected to the network or connected through power electronics.

1.1.2.2 Maximum capacity and the voltage level at the connection point

Power-generating modules are divided to:

- type A,
- type B,
- type C, and
- type D,

regarding their maximum capacity, as well as the voltage level at the connection point. Namely, for voltage levels less than 110 kV power-generating modules can be of type A, or type B, or type C, or type D. For voltage levels greater or equal to 110 kV only type D power-generating modules can be. The categorization in not done for the modules of maximum capacity less than 0.8 kW, and therefore the compliance tests with grid connection requirements are not needed for them.

The limits for maximum capacity thresholds according to RfG are listed in Fig. 1. In general, these limits are different in different synchronous areas, except in Continental Europe and Great Britain. In Continental Europe and Great Britain the maximum capacity thresholds from which the power-generating modules are of type B, type C and type D are: 1 MW, 50 MW and 75 MW, respectively.

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Synchronous areas	Limit for maximum capacity threshold from which a power-generating module is of type B	Limit for maximum capacity threshold from which a power-generating module is of type C	Limit for maximum capacity threshold from which a power-generating module is of type D
Continental Europe	1 MW	50 MW	75 MW
Great Britain	1 MW	50 MW	75 MW
Nordic	1,5 MW	10 MW	30 MW
Ireland and Northern Ireland	0,1 MW	5 MW	10 MW
Baltic	0,5 MW	10 MW	15 MW

Fig. 1 Limits for thresholds for type B, type C and type D power-generating modules

However, national maximum capacity thresholds are proposed by the relevant TSO, and approved by the relevant regulatory authority or state. In this process relevant TSO should coordinate with DSOs (distribution system operators) and adjacent TSOs, and also conduct a public consultation. Therefore, national maximum capacity thresholds can be different, even in some EU states, as shown in Fig. 2. For example, all three low maximum capacity tresholds are low in Italy, and this is marked by green arrow in Fig. 2, while in some countries the tresholds are quite different and can be characterized as low (green cyrcles), and/or medium (yellow cyrcles) and/or high (red cyrcles) .

state	national maximum capacity thresholds for power-generating modules		
	type B	type C	type D
Germany	135 kW	36 MW	45 MW
Denmark	125 kW	3 MW	25 MW
Spain	100 kW	5 MW	50 MW
France	1 MW	18 MW	75 MW
Italy	11,08 kW	6 MW	10 MW
Austria	250 kW	35 MW	50 MW
Hungary	200 kW	5 MW	25 MW
Romania	1 MW	5 MW	20 MW
Bulgaria	1 MW	5 MW	20 MW

Fig. 2 Some of the national maximum capacity thresholds

The selection of national maximum capacity thresholds is very important because it strongly affects the set of requirements for compliance tests. Namely, RfG defines a set of requirements for compliance tests for each type of power-generating modules. The relationship between the sets of requirements for different types of modules is:

$$\text{Set of requirements for a type A} \subset \ldots \text{type B} \subset \ldots \text{type C} \subset \ldots \text{type D} \ . \quad (1)$$

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The choice of the maximum capacity thresholds depends primarily on the attitude of interested parties:

- electricity consumers,
- system operator,
- investors as potential small and large producers of electricity, etc.

In general, electricity consumers and system operator prefer lower maximum capacity thresholds that imply the larger sets of requirements for most of potentially new power-generating modules and therefore less likely to cause problems in operation of the future grid with distributed generators connected. On the other hand, investors/producers of electricity would like the thresholds to be higher in order to avoid numerous compliance tests and complicated procedures of operational notifications. Therefore, the task of the relevant regulatory authority in one country is to compromise, and to propose national maximum capacity thresholds. Because compromise is very difficult to achieve, some countries have not adopted maximum capacity thresholds.

1.1.3 Requirements for compliance tests

Division of power-generating modules to type A, type B, type C and type D, and to synchronous power-generating modules and power park modules, is depicted in Fig 3. Type A, type B, type C and type D power-generating modules have general requirements for compliance tests. Depending on electricity generation technology, additional requirements for compliance tests should be fulfilled for synchronous power-generating modules and for power park modules (of specific type: B, C and D). It should be emphasized that type A power-generating modules have only general requirements for compliance tests regardless of which electricity generation technology they use.

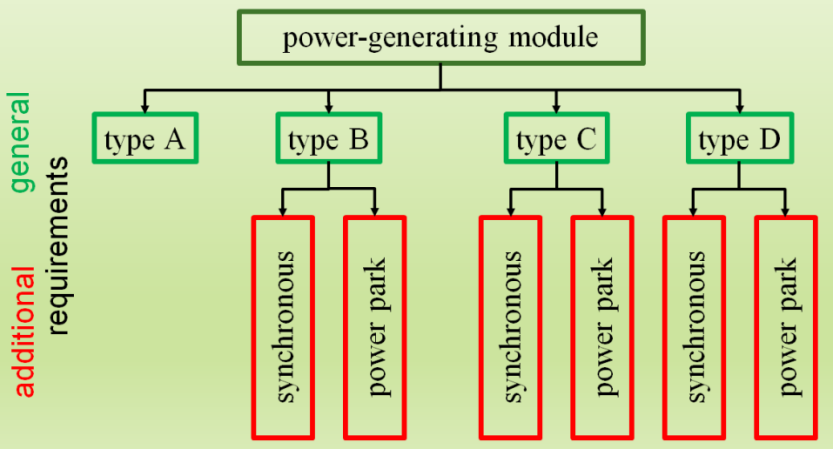

Fig. 3 Division of power-generating modules

Both general and additional requirements can be complete, incomplete and optional requirements for compliance tests. The difference between these three kinds of requirements is explained in Section 1.1.3.6.

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1.1.3.1 *General requirements for type A power-generating modules*

Applying three color denotations, the general requirements for type A power-generating modules can be listed as follows:

- Frequency stability
    - with regard to frequency ranges,
    - with regard to the rate of change of frequency withstand capability;
- Limited frequency sensitive mode — overfrequency (LFSM-O);
- Active power stability;
- Active power reduction with falling frequency;
- Remote control;
- Automatic connection to the network.

1.1.3.2 *General requirements for type B power-generating modules*

As mentioned before, the set of requirement for type A power-generating modules is the subset of the set of requirement for type B power-generating modules (1). Therefore, general requirements for type B modules include all general requirements for type A power-generation modules and following (incomplete) requirements:

- Frequency stability with regard to remote control of active power output;
- Robustness of power-generating modules with regard to fault-ride-through capability (FRT);
- System restoration;
- System management
    - with regard to control schemes and settings,
    - with regard to electrical protection schemes and settings,
    - with regard to protection and control devices organization.

1.1.3.3 *General requirements for type C power-generating modules*

General requirements for type C power-generating modules comprehend almost all general requirements for type B modules, except frequency stability with regard to remote control of active power output. Also, general requirements for type C power-generating modules encompass one complete, eleven incomplete and four optional requirements:

- Frequency stability
    - with regard to active power controllability and control range,
    - with regard to active power manual control;

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- Limited frequency sensitive mode — underfrequency (LFSM-U);
- Voltage stability — the module has to be able to disconnect from the net automatically when the voltage drops to predefined system value;
- Robustness of power-generating modules
    - with regard to power oscillations,
    - with regard to voltage and frequency,
    - with regard to auto-reclosures on network lines;
- System restoration
    - with regard to black start capability,
    - with regard to the capability to take part in island operation,
    - with regard to quick re-synchronisation capability;
- System management
    - with regard to loss of angular stability or loss of control,
    - with regard to instrumentation (measuring equipment),
    - with regard to the simulation models,
    - with regard to the installation of devices for system operation and devices for system security,
    - with regard to minimum and maximum limits on rates of change of active power output,
    - with regard to earthing arrangement of the neutral point at the network side of step-up transformers (according to TSO's specifications).

1.1.3.4 General requirements for type D power-generating modules

General requirements for type D modules includes general requirements for type C except voltage stability, and four incomplete requirements:

- Voltage stability
    - to ramain connected within defined range of voltage,
    - TSO has the right to define the voltages at which the module have to be able to disconnect from the network properly;
- Robustness of power-generating modules with regard to fault-ride-through capability (FRT);
- System management with regard to synchronization.

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1.1.3.5 *Additional requirements*

Besides the above mentioned general requirements, additional requirements for compliance tests should be fulfilled for: synchronous power-generating modules of type B, type C and type D, and for power park modules of type B, type C and type D. Since (1) is also valid for the additional requirements, the lists of all of the requirements for specific power-generating modules are quite long, while the list for type C is longer than the list type B and the list for type D is the longest one.

1.1.3.6 *Forming the set of requirements*

In the case when the decision on harmonization with RfG is made, the relevant system operator form the sets of requirements for compliance tests in accordance with RfG and legel acts related to electrical network operation. Thus, relevant system operator:

- must take into account complete requirements,
- must supplement and/or precisely define incomplete requirements,
- must clearly emphasize the obligation to apply a certain optional requirement, as well as if necessary supplement and/or precisely define this optional requirement.

1.1.4 The procedure for power plant connection

The whole procedure for successful power plant connection to the grid can be summarized through four following steps:

- Technical requirements for grid connection of power-generating module are formed on the basis of a set of requirements for compliance tests known in advance. As mentioned before, this set of requirements for a specific power-generating module depends on its type (A, B, C or D) and electricity generation technology.
- Technical documentation is prepared.
- Power-generating module is build.
- Compliance tests are carried out.
- Operational notification is issued.

The next sections will clarify the last two steps of the procedure for power plant connection.

1.1.5 Carrying out the compliance tests

Each compliance test can be carried out in one of the following three ways:

- by equipment certificate issued by an authorized certifier,
- by field testing (measurements),

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- by testing on a simulation model (simulations).

at relevant system operator's decision, and in accordance with RfG and legel acts related to electrical network operation.

1.1.5.1 The role of the relevant system operator

For each compliance test, the relevant system operator is obliged to define precisely in advance the Procedure for compliance testing, and to introduce the facility owner to this testing. On the other hand, the facility owner is responsible for carrying out compliance tests.

The role of the relevant system operator in the process of carrying out compliance tests is significant and can be divided into following items:

- The operator is obliged to provide the facility owner with technical data and a simulation model of the network, to the extent necessary to carry out the requested simulations.
- The operator approves compliance tests advance-planned and announced.
- The operator may participate in compliance tests and record the relevant performance.
- The operator shall have the right to check power-generating module compliance by carrying out its own compliance tests.
- The operator assesses power-generating module compliance throughout the lifetime of the facility.
- The operator shall have the right to request that the facility owner carry out compliance tests according to a repeat plan or after any failure, modification or replacement of any equipment.

1.1.6 Operational notification

1.1.6.1 Operational notification of type A power-generating modules

In order to obtain operational notification, the facility owner submits an installation document per each power-generating module within the power plant, to the relevant system operator. However, the content of the installation document is specified by relevant system operator itself.

The installation document must contain equipment certificates issued by an authorized certifier, because the procedure of compliance testing in the case of type A is realized by inspecting the installation document, which must contain equipment certificates issued by an authorized certifier. If everything is in order, operational notification will be issued to the facility owner and the plant can be connected to the grid.

1.1.6.2 Operational notification of type B and type C power-generating modules

Operational notification of type B and type C power-generating modules is the same, and more complex than operational notification of type A power-generating modules. The notification

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encompasses the submission of a power-generating module document, which must contain a statement of compliance, to the relevant system operator. As in the case of type A power-generating modules, the facility owner submits separate power-generating module document for each power-generating module within the power plant, and the content of the power-generating module document is specified by relevant system operator.

The relevant system operator shall have the right to request that the facility owner includes the following in the power-generating module document, inter alia:

- itemized statement of compliance,
- equipment certificates issued by an authorized certifier, where these are relied upon as part of the evidence of compliance,
- simulation models (mandatory for type C),
- compliance test reports (for field testing and/or for testing on a simulation model),
- studies demonstrating steady-state and dynamic performance.

The relevant system operator, on acceptance of a complete and adequate power-generating module document, shall issue a final operational notification to the facility owner.

1.1.6.3 Operational notification of type D power-generating modules

The operational notification procedure for the connection of each new type D power-generating module is more complicated than the procedures for the connection of type B and type C power-generating modules, and comprises:

- energization operational notification,
- interim operational notification,
- final operational notification.

An energization operational notification:

- shall entitle the facility owner to energize its internal network and auxiliaries for the power-generating module by using the grid connection that is specified for the connection point;
- shall be issued by the relevant system operator, subject to completion of preparations including agreement on the protection and control settings relevant to the connection point between the relevant system operator and the facility owner.

An interim operational notification can be described by following items:

- It shall entitle the facility owner to operate the power-generating module and generate power by using the grid connection for a limited period of time.
- It shall be issued by the relevant system operator, subject to completion of the data and study review process.

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- With regard to the data and study review, the relevant system operator shall have the right to request the facility owner to provide items that are the same as the items listed in the case of the operational notification of type C power-generating modules.
- The maximum period during which the facility owner may maintain interim operational notification status shall be 24 months.
- The relevant system operator is entitled to specify a shorter interim operational notification validity period.
- An extension of the interim operational notification shall be granted only if the facility owner has made substantial progress toward the full compliance.
- Outstanding issues must be clearly identified at the time of requesting extension.

A final operational notification is the final aim of all owners of the new power plants. It can be fully described as follows:

- A final operational notification shall entitle the facility owner to operate a power-generating module by using the grid connection.
- It shall be issued by the relevant system operator, upon prior removal of all incompatibilities identified for the purpose of interim operational notification status and subject to completion of the data and study review process.
- For the purposes of the data and study review, the facility owner must submit the following to the relevant system operator:
    - itemized statement of compliance,
    - compliance test reports (for field testing and/or for testing on a simulation model),
    - updated technical data, simulation models and studies, including the use of actual measured values during testing.

Limited operational notification is one more term regarding operational notification of type D power-generating modules. Namely, facility owners to whom a final operational notification has been granted shall inform the relevant system operator immediately in the following circumstances: the facility is temporarily subject to either significant modification or loss of capability affecting its performance; the failure of equipment leads to non-compliance with some relevant requirements. In the case when facility owner reasonably expects the stated circumstances to persist for more than 3 months, the owner shall apply to the relevant system operator for a limited operational notification. This notification shall be issued by the relevant system operator and shall contain the following information:

- unresolved issues justifying the granting of the limited operational notification,
- responsibilities and timescales for the expected solution,

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- maximum period of validity which shall not exceed 12 months.

It must be emphasized that the final operational notification shall be suspended during the period of validity of the limited operational notification.

1.1.7 Contribution to development of low carbon technologies and sustainability

The significance of this course topic is big because huge number of new power plants are planned to be build and connected to the grid all over the Europe. The plants will mainly use low carbon technologies and contribute to sustainable future of the planet. This is why it is very important to help the facility owners to have instructions for the entire process of power plant connection to the grid, such as the content of this course topic.

1.1.8 Highlight on application in industry

The presented matter has the applications in industry. Namely, facility owners should be very well informed in details about all requirements for compliance tests of their new power-generating modules planned to be connected to the grid, as well as about all steps in the process that lead to final operational notification issued by TSO. This knowladge is of crucial importance for them, in order to ensure an economically justified investment.

The employees in TSOs can also apply the knowladge elaborated in this course topic, as a reminder of the sets of requirements for compliance tests for different types of power-generating modules. Furthermore, they can use step lists within operational notification procedures for new modules of certain types.

1.1.9 Contribution to development of skills and competences

This course topic has the contributions to development of skills and competences for both industry employees and students. Industry employees can study about the procedure for power plant connection to the grid including: technical requirements for grid connection of power-generating modules of different types, preparation of technical documentation, carrying out the compliance tests and operational notification of power-generating modules of certain types. The students of electrical power engineering can study the matter related to the connection of new power plants to the grid and have a comparative advantage in finding a job.

1.1.10 Conclusions

The presented matter related to the compliance tests for power plants summarizes the requirements for compliance tests for different types of power-generating modules and explains the procedures for power plant connections to the grid. The students of electrical power engineering can use the knowladge elaborated in this material in their future jobs in power

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industry. Also, facility owners can use it as the guide how to obtain operational notification of their new power plants. Taking into account today's requirements for the mass use of dispersed generators that mainly use low carbon emission technologies, the contribution of this course topic to the development of competencies for industry employees and other stakeholders is big.

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