Chapter 2
Grid Codes: Goals and Challenges

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Abstract Electric power has always been one of the driving forces for progress in human life. This has popularized electric energy as the most utilized form of energy. However, dispersed locations of energy resources and continuously increasing demand of electricity have led to a large electric power transmission network across the landscape. To operate the system effectively, a large number of components, such as protection systems, monitoring systems, operational procedures, etc. are required to work in a synchronized and efficient manner; otherwise, contingencies may arise in the system. Development and integration of renewable energy sources into the existing power system has enhanced the complexity in the network. Efficient operation of this complex network is a tedious task for the authorities. Thus, to simplify the planning, operational, and other tasks, grid codes have been developed. Grid codes are the rules laid by the authorities for all its stakeholders, i.e., the users and power generating stations for connecting to the network and operate as per the standards. These grid codes implement the regulations for smooth operation of the grid and its connected components. It implies to the existing and future plants. This chapter gives an overview of the grid codes, its various components and their development considering integration of renewable energy into the grid. Various aspects, such as classification and specifications of the grid codes, the anomalies that exist between the grid codes developed and standards used in conventional power plants are discussed in this chapter.

Keywords Grid codes · Renewable energy sources · Thermal power plants · Nuclear power plants

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2.1 Introduction

Electric power grid is the largest man-made system in the world. A variety of different components, such as synchronous generators, transmission lines, switches, relays, active/reactive compensators, and controllers etc., are the main constituents of this system [1]. Owing to its complex nature, proper planning, and design become essential for the operation of the power system. Traditionally, a single authorised-body designs and plans the type, location, capacity of new power stations and their connection requirements to the grid.

Recent trend of penetration of the renewable energy sources to the grid has further enhanced the complexity of the network. Due to their stochastic nature, their integration has added more uncertainty to the grid, leading to increased concerns related to the accurate prediction of generation and control of power flow [2]. In addition, the deregulation (privatisation and liberalisation) in the electricity sector have invited more generation and supplier entities to meet up the ever-growing demand of electricity [3]. This addition of the new generation schemes along with a large number of competitors has led to following new challenges for the proper planning and operation of the present and future power systems [4]:

- Increased level of complexity,
- Stochastic nature of power transfer capabilities, and
- Bidirectional power flow across the system.

Inclusion of these renewable energy sources and stringent requirements by the sensitive loads has raised serious concerns related to the security, reliability, stability and efficiency, viz., adequate dimensioning, establishment, connection, and operation [5]. To safeguard, the electric power systems, against failures and address the issues raised, rules and regulations are required. These rules act as standard procedures and requirements for including or prohibiting connection of the generation plants and loads to the grid. The rules should be applicable to the both, new and existing, generation plants and users, who are interested to connect to the grid. Grid codes are attempts in this direction to ensure supply quality for the consumers.

Grid codes, also known as the ‘interconnecting guidelines’, are the instructions, which specify technical and operational characteristic requirements of power plants and different parties involved in the production, transportation and utilization of electric power. In other words, these are the technical requirements to interconnect new generating plants to the local or bulk systems [3, 6, 7]. With the generation deregulation in USA in early 1990s, these guidelines started appearing in USA and other countries [7]. These rules are laid by experts in the area of transmission operation and control from the very early time. As transmission acts as the link between the generation and distribution, handling bulk of the power, grid codes give prime importance to it. The main goal for development of these codes was to formalize the criteria, earlier used by the predecessor utility organizations, to specify the details of the power generation equipment and connection

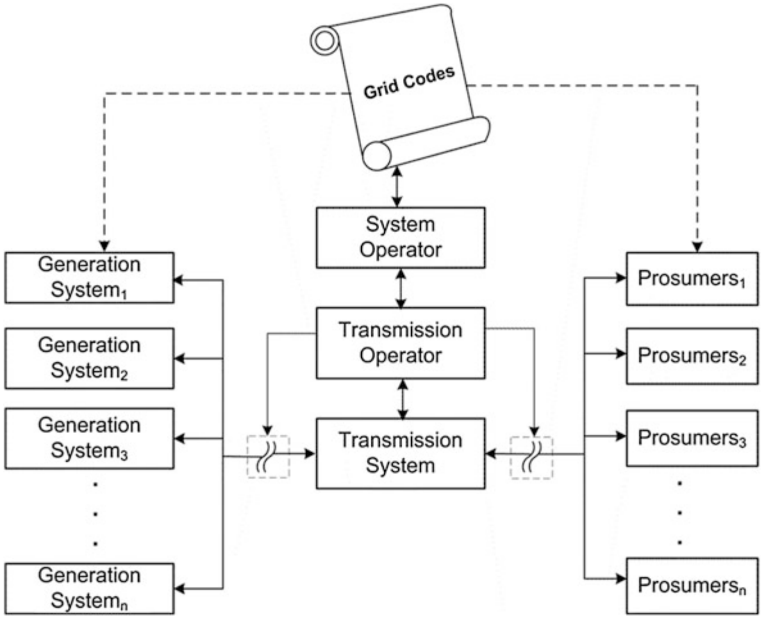

Fig. 2.1 Diagram showing the importance of grid codes in power system [9]

requirements for their connection to transmission system. Also, it attempts to establish and maintain compliance of the new generation plants, with recognized industry standards, except in some cases, where some sites requires stringent standards [7]. As formation of these codes is controlled by the local regulatory authorities, under different legal and technical environment, the requirements and specifications mentioned in the document may vary. The reason for variation in the grid code may be due to different system types or grid characteristics in different countries [3].

The importance of the grid codes in any power system can be easily explained with the help of Fig. 2.1. It depicts that grid codes act as a standard document for all the entities interacting in power systems. It is the responsibility of the system operator to check whether the codes are being obeyed at every level or not. The next component is the transmission operators, who have direct control over the transmission system. Activities such as increasing awareness regarding following the codes and taking necessary steps for not obeying it are the duties of the transmission operator. Based on the compliance report provided by the operators, the generating station or prosumer is permitted to make a connection with the transmission system. The term 'prosumer' is referred in the context of the smart grids, as in smart grids, the consumer is likely to *pro*duce as well as consume electricity [8].

Although, grid codes may appear as a simple document, they address all significant concerns related to the grid. This chapter attempts to discuss the main

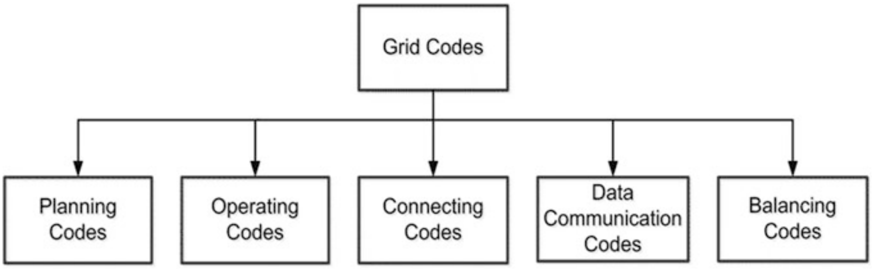

Fig. 2.2 Classification of the grid codes [6]

areas covered under the grid codes. In Sect. 2.2, classification of the grid codes and their various components are discussed in detail. Relevant issues regarding the frequency response, reactive power capabilities, safety, security and efficiency of the grid are addressed. The challenges regarding incorporation of renewable energy sources are discussed in Sect. 2.3. Section 2.4 presents existing grid codes, and the trend for development of grid codes and certification procedure for the renewable energy sources, especially wind power generation and its integration, etc. In Sect. 2.5, the issues of compliance between the conventional generation schemes and grid codes are discussed. The discussions made in this chapter are based on the following grid codes:

(1) USA: Interconnection for Wind Energy [10]
(2) India: Indian Electricity Grid Code [11]
(3) Great Britain : The Grid Code [6].

However, in general, it is based on the inferences drawn from [6], being a recent grid code, and clearly representing the requirements and classifications.

2.2 Specifications of the Grid Codes

Grid Codes are instructions that describe the technical and operational characteristic requirements of the power plants. These codes are the guidelines, to be followed by any user from, installing new power plants or making any alteration in the existing power plants to the, connection of the different components of the power system to the grid. Since, these instructions involve a variety of components to be dealt with the grid codes; they are classified into different components [7], as shown in Fig. 2.2. This classification simplifies the understanding and requirements for implementation and development of the new grid codes.

Amongst the various components, planning codes (PC) deal with dimensioning, planning, and development, etc. of the power plant and other equipments that are, required to be connected between the user/generation plant and the transmission system. The connecting code (CC) discusses the connection requirements and conditions to remain connected to the grid. The operational requirements of various equipments in the power systems are dealt by the operating codes (OC). Data communication codes (DCC) deals with the requirement for data storage, amount of data storage and quantities to be stored. Balancing codes (BC) discuss the steps taken by authorities, to maintain the power balance between load and generation. Detailed analysis on these different classes of grid codes is presented in the following sub-sections.

2.2.1 Planning Codes (PC)

Planning codes (PC) are the vital component of the grid codes. These codes are implemented at the planning or modifying stages of power plants. It may involve substation or connection site, transmission lines or other facilities connecting the connection site to remainder of the transmission network. It discusses the technical specifications and procedures for planning of the system. At initial stages of the project, transmission operator checks abidance of the PC by user. It may accept or decline the project, depending upon the fulfilment of the grid code criteria. In most cases, the codes are specified either as per the established standard, or in form of a bilateral agreement, between the authorities.

As per the grid code [6], details (generally required by the authorities at initial stages) can be given as:

- Description of the plant or apparatus being installed or modified,
- Standard planning data,
- Desired completion date of the proposed development, and
- Connection entry capacity and transmission entry capacity.

At initial stages, all the information exists in form of data. Utilizing this, data interaction between transmission operators and the power generation plant takes place. However, for lucid understanding and uniformity, the data should be in the format, as prescribed in the PC. Only then, a bilateral agreement between the generation plant and operator may take place. The offer is made for a fixed period of time, which may vary as per the licence standard (varies from country to country). The time for development may vary depending upon magnitude, complexity, nature, and location of the transmission system project.

The objectives of the PC can be summarized as:

(a) Promotion of interaction between different entities involved in the transmission system for discussion on proposals affecting, directly or indirectly, and performance of the transmission system.
(b) Collection of information for planning and development in relevance to the standards and existing facilities.
(c) To increase awareness about licensing standards in planning and development.

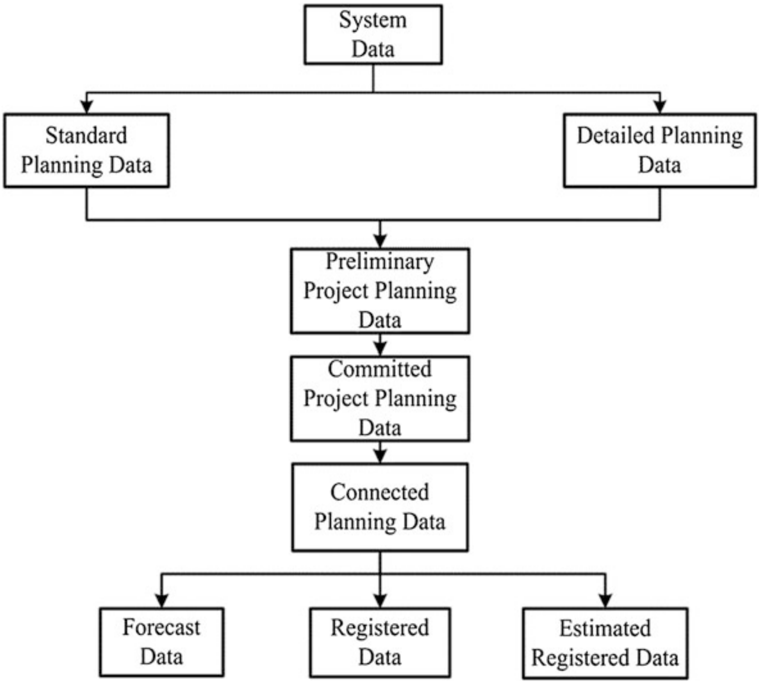

Fig. 2.3 Classification of data under planning codes [6]

(d) Spreading knowledge about various duties, under the licences, for proper operation of transmission system.

To understand PC, the data requirement is divided into two parts, namely [6]:

(a) Standard planning data, and
(b) Detailed planning data.

Standard planning data is general-purpose data, required at initial stages of the project for, having information about the planning stages. Thus, some data may slightly change due to implementation issues. On the other hand, detailed planning data is specific data, satisfying a particular requirement of the PC. This type of data is required at advanced stages on the normal time scale, to enable transmission operation. Figure 2.3 shows further classification of these two forms of data, as following:

- *Preliminary Project Planning Data*: It is required at initial stages of the project, involving quantities like, plant name, details, ratings, etc. Due to its initial stage requirements, it is termed as preliminary data.
- *Committed Project Planning Data*: After planning stages, the data required, is termed as committed project planning data. Generally, it involves the updated and new data, obtained after initialization of the project.

Table 2.1 Specifications of different components represented in SLD

Components	Specifications
Transmission circuitry	Rated voltage (kV), operating voltage (kV), positive phase sequence reactance, positive phase sequence resistance, positive phase sequence susceptance, and zero sequence impedance, both self and mutual
Transformers	Rated voltage (kV), voltage ratio, winding arrangement, positive sequence reactance (maximum, minimum and nominal tap), positive sequence resistance (maximum, minimum and nominal tap), and zero sequence reactance
Interconnecting transformers	Tap changer range, tap change step size, tap changer type (on load or off load), earthing method, and direct resistance and reactance and Impedance (if not directly earthed)
Reactive compensation	Connection node, voltage rating, power loss, tap range, connection arrangement, mathematical representation in block diagram format to control any dynamic compensation plant, HV node, LV node, control node, nominal voltage (kV), target voltage (kV), voltage dependent Q limit, and normal running mode

- *Connected Planning Data*: After initialization of the project, network operator updates the value estimations for planning purpose with actual values after reasonable practicing.

The connected planning data is further divided into three types namely:

(i) *Forecast Data*: Those items of standard planning data and detailed planning data which will always be forecasted are known as forecast data.
(ii) *Registered Data*: Standard planning data and detailed planning data, which become fixed upon connection, are termed as registered data.
(iii) *Estimated Registered Data*: Data estimated for a particular term are termed as the estimated registered data.

It is necessary to specify the dates for these data [6].

Standard planning data that is, required at initial stages of the project, include the following components:

- Single line diagram (*SLD*),
- Current carrying capacity of the apparatus, and
- Connection point.

(a) *Single line diagram* (*SLD*): For a particular portion of transmission system, an SLD should clearly depict its circuitry. General information, such as, substation names, circuit breakers, phasing arrangements, rated voltage (kV), operating voltage (kV) etc. should be specified. However, the amount of data required under various categories may vary from country to country. The other various specifications needed to be specified in the transmission system are summarized in Table 2.1 [6].

Table 2.2 Specifications of different components in SLD at connection point

Category	Description
Short-circuit contribution	Type of connection (direct or indirect) and bus bar arrangement
Generator	Registered capacity, output usable, system constrained capacity, and minimum generation
Generation performance chart	Specified in the charts
Rated parameter data	Ratings of different components connected
For all generating units	Rated MVA, rated MW
Synchronous generating units	Short circuit capacity, direct axis reactance, inertia constant—MWs/MVA;
Transformer units	Step up transformer, rated MVA, positive sequence reactance (at maximum, minimum and nominal tap)
Forecasted data	Peak day on each of the user's user system, day of peak (date and time), day of minimum (date and time)
Unit control	Maximum droop (%), normal droop (%), minimum droop (%), maximum frequency deadband(±Hz), minimum frequency deadband(±Hz), maximum output deadband(±Hz), normal output deadband(±MW), minimum output deadband(±MW)
Frequency setting of unit droop controller	Maximum Hz, normal Hz, and minimum Hz

(b) *Load/current carrying capacity of the apparatus*: Under abnormal operating conditions, the different components connected to the transmission line may have to bear the extra amount of current. Therefore, to protect the components, it is necessary to specify the current carrying capacity of the equipments. The current carrying capacity of the components is an indication of the short-circuit capacity of the planned facility. Thus, it may be specified either as short-circuit capacity or Ampere ratings.

(c) *Connection point*: The connection point is decided according to the connecting capacity of the transmission system. Based on this capacity, the location for plant connection is decided.

In detailed planning data, the data related to the operations, viz. usable capacity during the operation, operating range of the connected equipment, etc. of the grid is provided. Other different components, usually specified under the detailed planning data, are shown in Table 2.2 [6].

2.2.2 Connection Codes (CC)

Completion of plant as per the planning codes does not ensure the eligibility of the plant/user for connection to the grid. To connect to the grid, it is essential for the plant authorities to obtain clearance as per the connection code (CC). These codes specify the minimum technical, design and operational requirements, for the plant to obey and connect to the connection site/interface point prior and start operating. These requirements are to be compiled and checked by the transmission operator under the supervision of the system operator. Objective of the CC is to ensure that the specifications of system comply with its statutory and transmission licence obligations.

These codes are applicable to the generators/power stations, network operators, different converter station (acting as an interface between the generation and transmission systems), and other externally connected operators. To test the compliance for their connection to grid, certain parameters are checked to ensure proper operation of the transmission system. Conditions laid before permitting connections to the grid are specified as per the standards or bilateral agreement. Only those users/power generation plants are allowed to connect to the grid who complies with these norms, considered in terms of following parameters:

(a) Grid Frequency Variations

Different components connected in a grid are connected synchronously, i.e., at same frequency. Any variation in frequency will lead to loss of this link and separation of the different components. Thus, it is crucial to maintain frequency within the prescribed limits. The bands for frequency described in the grid codes may vary with region; for example, for a 50 Hz transmission system operation band is 49.5–50.5 Hz, which may be allowed to extend from 52 to 47 Hz, in exceptional circumstances [6]. This wide range under exceptional circumstances is further divided into smaller bands as shown in Table 2.3.

(b) Grid Voltage Variations

For efficient operation of electrical equipment, it is essential to maintain the voltage levels. The permissible voltage levels vary as per the agreement. However, the allowable voltage variation varies with the voltage level. At higher voltage levels, the voltage is not allowed to vary as much as at the lower levels. For example, at higher voltages, say 400 kV, a variation of ± 5 % is permissible unless abnormal conditions prevail. Under abnormal conditions, a voltage variation of ± 10 % is permissible, but voltage variation from ± 5 to ± 10 % is permissible for about 15 min, only. For lower voltages, like 275 and 132 kV at connection site a variation of ± 10 % of the nominal value is permissible unless abnormal conditions prevail. Under fault conditions, voltage may collapse transiently to zero at the point of fault until the fault is cleared. The permissible variation of voltages for different voltage levels [6] is presented in Table 2.4.

(c) Voltage Waveform Quality

Most of the components present in the power system are non-linear in nature. However, the equipment, specially meters and protection devices, are designed for their use with linear equipment. The generators, power station equipment, and loads, connected to the transmission system may operate erroneously, under the influence of waveform distortion. Thus, it becomes critical to put a limit on the waveform distortion at the connection site. The most common distortions encountered are discussed below:

Table 2.3 Permissible frequency variation under exceptional circumstances [6]

Frequency range (Hz)	Requirement
51.5–52	Operation for a period of at least 15 min is required each time the frequency is above 51.5 Hz
51–51.5	Operation for a period of at least 90 min is required each time the frequency is above 51 Hz
49.0–51	Continuous operation is required
47.5–49.0	Operation for a period of at least 90 min is required each time the frequency is below 49.0 Hz
47–47.5	Operation for a period of at least 20 s is required each time the frequency is below 47.5 Hz

Table 2.4 Permissible voltage band at different voltage levels [6]

Nominal voltage (kV)	Normal operating range
400	400 kV ± 5 %
275	275 kV ± 10 %
132	132 kV ± 10 %

(i) Harmonic content

In the grid, the switching of components and non-linear loads, connected to the system, induce harmonics in the system. The different generation, transmission and distribution equipment connected under the influence of harmonic distortion operate erroneously. However, for proper operation of the transmission system, the electromagnetic compatibility levels of harmonic distortion should be within the prescribed limits. These limits are to be either based on the IEEE/IEC standards or described clearly in the bilateral agreement. To obey these limits, it is vital to limit the harmonic content at a particular connection point and its emission to the rest of the network. Thus, while considering the harmonic limits in a system, it is important to consider:

(1) Location of new connections,
(2) Position of existing connections, and
(3) Number of connections at the node.

(ii) Phase unbalance

Phase unbalance is a major common problem in the grid. Due to inherent structural and loading properties of the transmission system, it is nearly impossible to remove it. It severely affects the components connected to the transmission system, especially the induction machines [12]. Therefore, to maintain the unbalance within the tolerable limits, certain limitations are imposed on the power plants and users. For example, in England and Wales, the limit for unbalance is 1 %, whereas it should be below 2 % in Scotland, unless abnormal conditions prevail. For off-shore connections, the limits are described in the bilateral agreement, in general.

(iii) Voltage fluctuations
Voltage fluctuations are the variation in the voltage magnitude. It arises mainly due to the switching of heavy loads and different components connected directly to the point of common coupling. However, to protect the equipment and limit the voltage fluctuations, limit is defined in the bilateral agreement. Design of the connections between transmission system and generating units, network operator's user system, etc. should be consistent with the licence standards. For example, in England and Wales, for onshore transmission system, it shall not exceed 1 % of the voltage level for repetitive step changes. In case of abnormal conditions, voltage excursions up to a level of 3 % may be allowed; however, it should be safe for the transmission system.

For offshore transmission system, the limits are set out in the agreement. In relation to the connection point, the plant and apparatus must comply with the requirements specified in the bilateral agreement.

(d) Protection System
Protection system is a vital component in operation of the grid. It separates the faulty components of the system from the healthy part. Since, the transmission system is complex in nature; the protection devices should have co-ordinated control. The co-ordination should be with minimum fault clearing time, in accordance with the bilateral agreement. At higher voltage system, the fault clearing time is minimum, which may increase with lesser voltage levels. For example, at 400 kV the permissible limit is 80 ms, whereas, at 132 kV, it is 120 ms.

In case of the converter stations, the owner is required to install the circuit breaker fail equipments with settings in accordance with the bilateral agreement. The important protection schemes to be considered in the protection system are:

(1) Loss of excitation,
(2) Pole-slipping protection,
(3) Signals for tariff metering,
(4) Work on protection equipment, and
(5) Relay settings.

(e) Plant Performance Requirements
The plant, either thermal or renewable energy is required to follow the plant performance norms to remain connected to the transmission system. The plant should maintain performance in terms of frequency, voltage and power level, as per the requirements of the agreement.

For onshore installed synchronous generator units, the units must be capable to operate continuously, between the limits of 0.85 power factor lagging to 0.95 power factor leading at the generator terminals. However, at operating conditions other than the rated value, the units must supply continuous power at reactive power capabilities identified on the generator performance chart. In addition, the generator connected should have the connection entry capacity of above rated value, during which:

(i) the reactive power capabilities must be at a minimum of 0.9 power factor,
(ii) all active power output levels in excess of rated value or as per the bilateral agreement.

For such a generator with apparent power rating of less than 1600 MVA the short circuit ratio should not be less than 0.5, whereas above 1600 MVA, it should not be less than 0.4.

For all generators, at offshore grid entry point of the LV side, the active power output levels should be maintained at zero transfer of reactive power. The steady state tolerance on reactive power transfer, to and from an off shore transmission system, should not be greater than 5 % of the rated value, or as per the reactive power capability specified in the bilateral agreement.

Further, the different generation units, converter stations, etc. must be capable of continuously maintaining constant active power output for system frequency changes.

(f) Excitation and Voltage Control Performance Requirements

The generators connected to the transmission system shall maintain the terminal voltage as per the grid voltage variation specified in the agreement. To implement this, it is necessary to implement continuously acting automatic excitation control system. This provides the necessary control, to generator, for maintaining constant terminal voltage without causing instability over the entire operational range.

The continuously acting control system should be capable of providing the reactive power control or an alternative reactive capability, as specified in the agreement.

(g) Steady State Load Inaccuracies

To regulate the frequency variation, it is important to have error free characteristics of the load. The major application of load data is in forecasting the load. In [6], at steady state the upper limit on the standard deviation in the load, over a period of 30 min, is fixed at 2.5 % of the generation capacity.

(h) Negative Phase Sequence Loadings

Due to faults and unbalanced load connected etc., negative sequence current flows in the generator. This affects the operation of the synchronous generator. Therefore, it is important for the generator to withstand the negative phase sequence voltages/currents, without tripping of the circuit breaker.

(i) Communication Plant

In a certain situation, communication between the operators and the plant is required. To achieve this, a communication link is required between the two. The system should be planned in such a way that both calling and receiving parties can signify the priority and prioritise disconnect tones.

2.2.3 Operating Code (OC)

Operational phase of the power plant begins after obtaining clearances for the planning and connection codes from the authorities. Operation is a vital part of the power system. Any improper operational event may lead to failure of the equipment and damage to the connected systems. Thus, to keep the system working, while maintaining the supply quality without any contingencies, it is essential for the plant operator to follow the operating codes. Operating codes are a part of the grid code, dealing with the operation of the plants connected to the transmission system. The operating code is further divided into following components [6]:

(a) Demand forecasting,
(b) Operational planning and data provisions,
(c) Testing and monitoring,
(d) Demand control,
(e) Operational liaison,
(f) Safety coordination,
(g) Contingency planning,
(h) Event information supply,
(i) Numbering and nomenclature of high voltage apparatus at sites, and
(j) System tests.

Since most of the operating codes involve time duration, equipment specification and other related requirements that, change with the local authorities, the details are not discussed here. A generalized discussion is rather presented to make clear understanding. For more details, readers can refer to the codes of their country.

(a) Demand Forecasting
Demand forecasting is an important aspect for operational purposes. It deals with the prediction of future demand in for a fixed duration of time as, specified by the grid codes. This information helps utilities in scheduling the generation to maintain the balance between generation and demand of power. It is usually performed for the active power, but the reactive power demand forecasting may also be required, for some authorities in their grid codes. The forecasting can also be used by different network operators and power suppliers for planning purposes.

Forecasting information is also required during the planning phase of the plant. But, the time durations for the demand forecasting and planning forecasting are different. In case of demand forecasting, the duration is in hours, whereas, for planning purposes, forecasting is done in years [6]. When the arrangement at a grid supply point is expected to be operated in separate sections, separate sets of forecast information are required for each section. The information required by the transmission operator, for a period specified in the grid code, is given as:

(a) Half-hourly annual peak transmission system demand,

(b) Output of the power station, and
(c) Forecasts of demand to be relieved by demand control.

Generally, the data is provided at a time-resolution of half-hourly basis along with the following information:

(i) Proposed date, time and duration of implementation of demand management,
(ii) Proposed reduction in demand by use of demand management, and
(iii) Proposed switching times, on daily basis.

The following factors are taken into account by National Grid Electricity Transmission (NGET) for daily demand forecasting [6], in programming phase and control phase as:

(a) Historic demand data including transmission losses.
(b) Weather forecasts with current and historical weather conditions.
(c) The incidence of significant events or activities, known to NGET in advance.
(d) Anticipated interconnection flows across external interconnections.
(e) Proposed demand control, equal to or greater than the demand control notification level, to be exercised by Network Operators with due information to NGET.
(f) Customer demand management equal to or greater than the proposed customer demand management notification level, to be exercised by suppliers with due information to NGET.
(g) Other information supplied by users.
(h) Anticipated pumped storage unit demand.
(i) Sensitivity of demand to anticipated market prices, for electricity.
(j) Demand taken up by station transformers.

(b) Operational Planning and Data Provision

Operation of the plant requires transmission of data, i.e., information at various levels. It includes information regarding the construction, maintenance, repair of the plant, and surplus generation available, etc. Each generator and interconnector operator has to provide this data in writing periodically, say weekly. This time scale may vary as per the grid codes. It is important to perform the operational planning of the plant to maintain the generation reserves for emergency conditions, like outages, maintenance schedule of plants, and financial planning, etc.

(c) Testing and Monitoring

The components of the generation plants and transmission systems require continuous monitoring and testing. The monitoring is essential to observe the operation of the equipment connected. The input and output of the plant should be according to the voltage, frequency and other quantities, as specified by the operational code. Testing is required to check the compatibility amongst the different components for input and output limits, and to obtain the dynamic parameters. If any failure in components is expected by obtaining this code, necessary measures are taken, to keep the system operational. The procedures to be followed and duration after which the component has to be tested are described in the bilateral agreement.

(d) Demand Control

Demand control is the reduction of demand in the event of insufficient availability of active power generation to meet the demand, or in emergency conditions. Primarily, it deals with following events [6]:

(a) Customer voltage reduction,
(b) Customer demand reduction by disconnection,
(c) Demand reduction,
(d) Automatic low frequency demand disconnection, and
(e) Emergency manual demand disconnection.

Demand control is essential for operation of the power station. It keeps the power station in a state of proper start up and shut down. The authorities authorized to perform the demand control, and the measures to be taken, are described in the agreement. Since, the forecasting data is required at a resolution of half an hour or less, the actions/implementations are also executed for the same time interval.

(e) Operational Liaison

Operational liaison is the requirement laid for information exchange, in operations or events, having an operational effect on the transmission system, generators or the users connected to the system. Monitoring the terminal voltage, frequency and their violation outside the statutory limits is important to check the status of the system.

Based on the monitoring and analysis, alerts are issued to the connected plants and users of the system about the shortages, problems or demand reductions. Also, the duration, as described in the data, allows users to be in a state of readiness, to react properly.

(f) Safety Coordination

Safety co-ordination is a major concern for the plant whether online or offline. It is, concerned with the safety of the people working in the plant and equipment. It prescribes the steps or procedures to be followed in order to keep the safety. Disregarding these instructions may lead to cancel/suspend the license for lifetime or certain duration.

Thus, the plant has to maintain a logbook for, recording the safety violations happened in the past and the measures taken to prevent their future occurrence.

2.2.4 Data Communication Code (DCC)

From planning to the operation of the power plant, exchange of information between the authorities, in form of data is important. The data from one end is communicated to other plants and to the transmission and system operator in the grid. The data communication refers to the

(a) Generators,
(b) Network operators,
(c) Converter station owners,
(d) Suppliers, and
(e) Users.

It is important to maintain the prescribed format, and security of the data.

2.2.5 Balancing Code (BC)

To keep the voltage and frequency variations within the statutory limits, it is important to control the reactive power flow and maintain the generation-demand balance, respectively. BC specifies the requirements to maintain the terminal voltage and frequency, under normal and emergency conditions.

In case of conventional power plants, such as, thermal and hydro, it specifies the opening and closing of the valves and gates to control the rotation of the turbines. Also, it specifies the time required by the mechanical devices, to respond to changes in the system. For voltage control, the amount of reactive power flow required, and time constant of the mechanical devices, depending upon the forecasting data is described in this code. Also, it specifies the permissible changes/rate of power transfer to the transmission system.

For renewable energy systems, such as wind or solar, the input to the system cannot be controlled. Therefore, it describes the control requirements, such as, rate of power generation, actions required to control the amount of power flow, and specifications of the controllers, etc.

2.3 Grid Code Challenges

The specifications of the grid code, as discussed in the Sect. 13.2, deal with the conventional generation schemes, such as, thermal or hydro power plants, etc. Inputs to the plants, i.e., steam and water, in case of thermal and hydro power plants, respectively, are controllable. However, in case of renewable generation schemes, the input is uncontrollable. For example, for wind energy generation the wind flowing cannot be controlled, and for solar energy, the presence/absence of sun cannot be controlled. Thus, the grid codes for such a system shall contain following information:

(a) Forecasting the availability of the renewable energy sources.
(b) Timing requirements for the decision-making and taking the necessary actions.
(c) Voltage level to be maintained at different input conditions.
(d) Frequency band to be followed.

(e) Characteristics, power ratings, and operational requirements of the converter stations.
(f) Protection system for these variable operating conditions.
(g) Characteristics and specifications of the controllers to control the amount of active and reactive power to be generated.

2.4 Grid Codes for Integration and Operation of Renewable Energy Sources

Nowadays, share of renewable energy generation in the total generated power is becoming more and more prominent. Because of the intermittent generation, improvements are important for the generation plant [13]. The discussions made in this section are based on the wind generation, primarily.

Sometimes, the power generation using the renewable sources can be a costlier affair. Therefore, governments provide incentive based schemes for its promotion. They help on the components of the generation system, especially the technology related to the development of controllers to generate the specified amount of voltage and frequency [14]. Also, it helps in training the personnel for the operation.

Operation of the wind generators, in line with the grid codes, is the prime concern for the plant owner. Thus, analyzing technical requirements for wind generators, due to their different physical characteristics from the synchronous generators becomes essential.

Along with the components of the grid codes, as discussed in Sect. 13.2, the major concerns for the wind energy systems can be described as [5, 15]:

(1) Low voltage ride-through capability,
(2) Reactive power control, and
(3) Power quality, etc.

(a) Low voltage ride-through capability: For any utility, connecting the wind energy systems to the transmission line is the prime concern. The wind technology is sensitive to the changes in voltage and power levels of the transmission system, which may lead to plant shut down. This sudden shutdown is a significant concern for the reliability of system, along with wind generators connected to the transmission system, as each transmission provider designs its own low voltage ride-through requirement, which affects the design and operation cost of the wind turbines. As a result, both wind generators and most transmission authorities prescribe the low voltage limits with time duration, or in other words, the characteristics that a wind farm, should have in order to connect to the transmission system. Wind generators demonstrating these characteristics are allowed to connect to transmission lines. In comparison to the synchronous generators, these

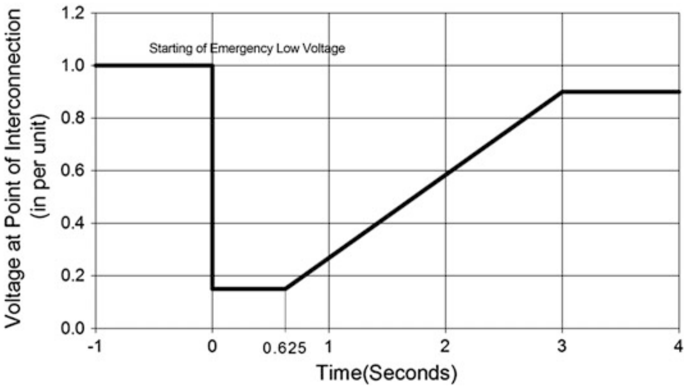

Fig. 2.4 Low Voltage ride through characteristics as per USA grid code [5]

characteristics are more important for wind energy system. The synchronous generators are connected to the automatic voltage regulators, to maintain the constant voltage, but wind energy systems do not have any such arrangements. The characteristics of the wind energy systems can be depicted, using the example of USA grid code [5] as shown in Fig. 2.4.

Figure 2.4 shows the time duration (in second) with the voltage (in per unit) at the point of interconnection. The characteristics show that the voltage dip occurs during 0 to 0.625 s, and then reaches to 90 % of the actual value in 3 s. The wind energy system, to be connected to the transmission system, should operate from 0 to 0.625 s, whereas the wind energy system is allowed to get disconnected from the system, when the system starts regaining the voltage level.

(b) Reactive power Control: For small wind energy system, the utilities are not much concerned for reactive power control, due to small requirement of reactive power. However, for larger wind generators, it is mandatory to maintain the reactive power levels. Such plants must be capable to provide the dynamic voltage support for interconnection to the transmission systems. Also, it is important for the wind energy service provider to maintain the power factor within the range of 0.95 capacitive to 0.95 inductive. To add the reactive power handling capabilities, the service provider can use the fixed/switched capacitors with consent of the transmission operator.

(c) Power quality: Amongst the various power quality problems, voltage sags are the major problems for the wind energy system. However, the transmission system operators demand the low voltage ride-through capability in these sources. Thus, huge investment has been made in developing devices, to support the wind system during voltage sags.

Doubly-Fed Induction Generators (DFIG) is one of the most popular technologies for wind energy systems, in which rotor and stator are connected to the transmission system through the converters. Voltage sags in the transmission side cause large currents to flow in the rotor and rotor side converter. If the required

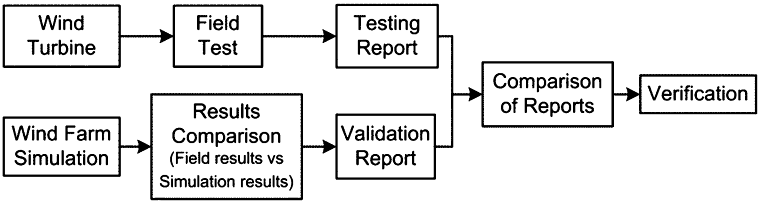

Fig. 2.5 General verification process [5]

voltage exceeds the maximum voltage of the converter, current control becomes tough [16]. To avoid damage to the converter switches, DFIG wind turbines are equipped with crowbars. When the rotor currents become high, it is bypassed through the crowbars. Then generator operates as an induction machine, with a high rotor resistance. Thus, it can support the grid during voltage sags [16, 17]. In case of short-circuits in the power system, large reactive power is required to recover the air gap flux. If not supplied, the induction generator may become unstable, leading to its disconnection from the transmission system [18, 19].

The other practical solutions, to deal with the voltages sags are:

- Static Var Compensator (SVC)
- Static Compensator (STATCOM).
- Dynamic Voltage Restorer (DVR), and
- Unified Power-Quality Conditioner (UPQC).

It is important for the wind energy system authorities, to select the techniques having capability to make a grid code complied system. The usefulness of these technologies has to be proven before their implementation in the system. The general verification process, adopted to verify that the wind system does not get disconnected during voltage sags, is shown in Fig. 2.5.

The general verification is performed in two steps, the field test and simulation test. If the reports of these tests are found in compliance with the grid codes, the construction, and operation of the wind farm is approved.

2.5 Grid Codes and Conventional Generation Schemes

The major concerns of the grid codes are the transmission system voltage and frequency variations. The transmission system operators demand the reliable compatibility, with all statutory warnings.

Synchronous generators are the most important component of the power system. It is vital for them to follow the specifications, and requirements, laid by the grid codes. However, in many cases the grid codes do not comply with the established international standards, such as IEC and ANSI [7].

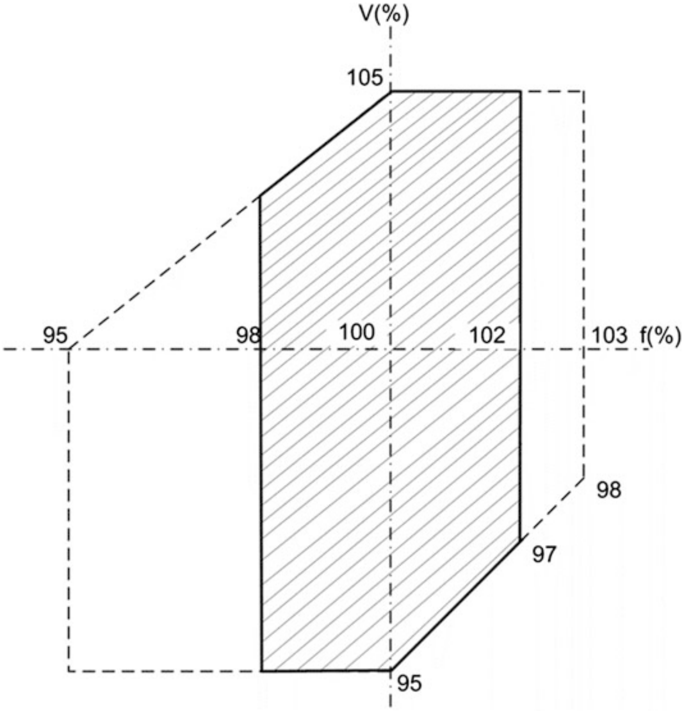

Fig. 2.6 Voltage and frequency variation [3]

The grid codes make no mention of the relevant generator or turbine industry standards and require capabilities that significantly fulfil industry norms. IEC 60034-3 [21] spells out the requirements for the design of turbines and the synchronous generators. For a turbine system, having synchronous generator systems connected to it, the voltage and frequency variation is shown in Fig. 2.6, where shaded portion represents the voltage-frequency characteristics for continuous operation, while unshaded portion shows the inoperable region.

As per the industry norms, synchronous generator terminal voltage can vary from 95 to 105 % of its nominal values. However, the foremost concern is frequency rather than the voltage. The permissible frequency variation is 5 % of nominal value, but the generator standards limit it from 98 to 102 %. Several other discrepancies can be clearly seen while observing the grid codes and industry norms for the synchronous generator systems [3].

Another major concern is the variation of cost involved, for changing the generator performance as per changes in the grid code. The short-circuit ratio or SCR, defined as the inverse of the value of its saturated direct axis reactance, helps in determining the generator leading reactive capability, with direct impact on the static stability [7].

For same apparent power, a higher value of the SCR depicts more ampere-turns in the field winding. However, the operation is limited by the temperature. A change of mere 0.1 % in the SCR increases the total machine volume by 5–10 %, which increases the cost of the system, depending upon the type of generator. Therefore, any minor change in the requirements of the grid code, may lead to typical changes in the design, and increased cost of the whole system.

2.6 Grid Codes and Nuclear Generation

Safety is a major concern for the nuclear power plants. Cooling of these plants is essential requirement. Thus, reliable power supply is required for the cooling purpose; otherwise, catastrophic situations, like FUKUSHIMA, may arise. This event showed the importance of maintaining auxiliary electric power to the nuclear power plants for safety.

The power supply to the nuclear power plants is divided into two components, i.e., mains or normal (unclassified, on a conventional island) and the emergency (safety classified, located in the nuclear island) power supply systems. Under normal conditions, the normal supply is used to cool the nuclear plant, whereas in case of emergencies, the emergency supply system is required to cool the plant. Thus, it is important to have continuous supply for the nuclear power plant.

Also, in case of blackout, nuclear power plants are unable to start of their own, due to the unavailability of power. It always requires a small power source to start with. Thus, reliability and availability of power are important in view of safety.

Usually, diesel oil based emergency power plants, producing limited amount of power are not reliable. To solve this problem, the nuclear power plants are supplied with dual supply, independent of each other, from the grid [20]. The standby connection should be able to provide the spinning reserve for operating the safety loads for cooling.

Supply quality is a major concern for the power plant. Voltage variation is an important factor for the operation of components connected in the nuclear power plant. Normally, a plant is designed to handle the slow variations in the voltage. To handle fast variations plants have to be specifically designed. Thus, it is important to maintain the voltage levels within the limit. The limits should be implemented for both, the normal and emergency power plants. Frequency variation is another important factor of power quality. It is a difficult component to be compensated. For a nuclear power plant, frequency variation is of utmost importance, as most of the motors in the plant are directly connected to the grid.

Thus, any variation in the frequency may affect the speed of the motor, indirectly related to the safety of the plant [20]. Thus, considering these factors, the grid code considering nuclear power plant should have:

- Strict rules for voltage variation,
- Strict rules for frequency variation, and
- Effective protection system, to maintain supply to the plant.

These requirements should be applicable for normal and emergency power plants, both.

2.7 Conclusion

In this chapter, a discussion on the grid codes is presented. Initially, the main classification of the grid codes is presented. Further, its classification into planning codes, connecting codes, operational codes, data communication codes and balancing codes, allows clear understanding of the grid codes. It signifies the various stages in the development of the plant and their requirements. Since, most of the codes are designed presuming conventional generation schemes, the requirements for developing grid codes for renewable sources are presented.

Further, the important components for the renewable energy plants are discussed. It shows that, power quality, low voltage ride-through capabilities, etc. are important component that needs to be addressed in the grid codes. In the end, a discussion on the conventional generation schemes and the grid codes is presented. It shows that a conflict may arise due to differences in the standards being followed by the plants. Further, a procedure on the requirement of the nuclear power plants and the grid codes is presented, to discuss the requirement of the strict rules for voltage and frequency variations, along with the protection system, for proper operation of the nuclear power plants. In summary, the chapter presents in-depth classification of the grid codes with its present status, compliance dilemma between the grid codes and conventional generation schemes, and requirements for their developments considering renewable energy sources and nuclear power plants.

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