MANUAL

ELECTRICAL SUPPLY AND GENERATION - DESIGN AND OPERATION

DEP 33.64.10.12-Gen.

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DESIGN AND ENGINEERING PRACTICE

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and gives recommendations for the design and operation of a plant network with partial or complete power supply from generation units. It gives minimum technical requirements for the design, engineering and installation on subjects related to the electrical infrastructure, the voltage and frequency control, generating units, protection and operation.

As the variety of local circumstances may differ tremendously, this DEP is not intended to give direct solutions. It deals mainly with the recommended engineering methodology, the determination of the operational constraints affecting equipment, the assignment of control requirements to generating units depending on their mode of operation within the plant's processes and the designing of voltage and active/reactive power control.

This DEP shall be used in conjunction with related DEPs:

- in the design stage;
- in the development of control strategies for voltage and active and reactive power control;
- in the development of operational strategies for power supply and a temporary transition to island operation;
- as outline for additional testing on the treated subjects;
- as outline for technical agreements with public electricity authorities.

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Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (9).

2. DEFINITIONS

2.1 GENERAL DEFINITIONS

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

2.2 TECHNICAL DEFINITIONS

2.2.1 General

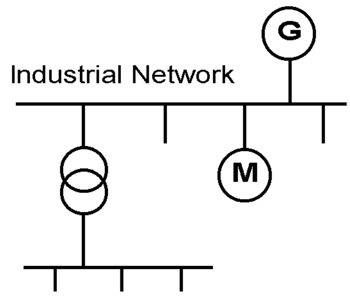
Availability (performance) IEC 60050 (191-02-05)	the ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided. This ability depends on the combined aspects of reliability performance, maintainability performance and maintenance support performance.
Availability, instantaneous IEC 60050 (191-11-01)	the probability that an item is in a state to perform a required function under given conditions at a given instant of time, assuming that the required external resources are provided.
Critical clearance time	the maximum allowable time period of a voltage drop caused by a three phase fault, without the occurrence of one or more pole slips at the synchronous generator or motor after fault clearance.
Electrical power network IEC 60050 (601-01-02)	particular installation, substation, lines, cables for the transmission and distribution of electricity. The boundaries of the different parts of this network are defined by appropriate criteria, such as geographical situation, ownership, voltage, etc.
External network	part of the *electrical power network* that is beyond the *point of common coupling*. In many cases the public network.
Interconnection IEC 60050 (601-01-11)	a single or multiple transmission link between transmission systems enabling electricity to be exchanged between these systems by means of circuits and/or transformers.
Isolation of a unit IEC 60050 (602-03-28)	the emergency measure consisting of the disconnection of a unit while preserving its ability to supply its own auxiliaries.
Maintainability (performance) IEC 60050 (191-02-07)	the ability of an item under given conditions of use, to be retained in, or restored to, a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.
Maintainability support performance IEC 60050 (191-02-08)	the ability of a maintenance organization, under given conditions, to provide upon demand the resources required to maintain an item, under a given *maintenance policy*.

Maintenance policy IEC 60050 (191-07-03)	a description of the interrelationship between the maintenance echelons, the indenture levels and the levels of maintenance to be applied for the maintenance of an item.
Point of common coupling	point(s) in an *electrical power network* which represent(s) the boundaries of administration and/or ownership between the different parts of that *electrical power network*.
Reliability (*performance*) IEC 60050 (191-02-06)	the ability of an item to perform a required function under given conditions for a given time interval.
Reliability IEC 60050 (191-12-01)	the probability that an item can perform a required function under given conditions for a given time interval.
Small island	electrical system consisting of a single generator and its auxiliaries with its primary and secondary circuits designed so that it is able to run on its own after *isolation of the unit.*
Spinning reserve IEC 60050 (602-03-15)	the difference between the total available capacity of all generating units already coupled to the system and their actual loading.

2.2.2 Networks

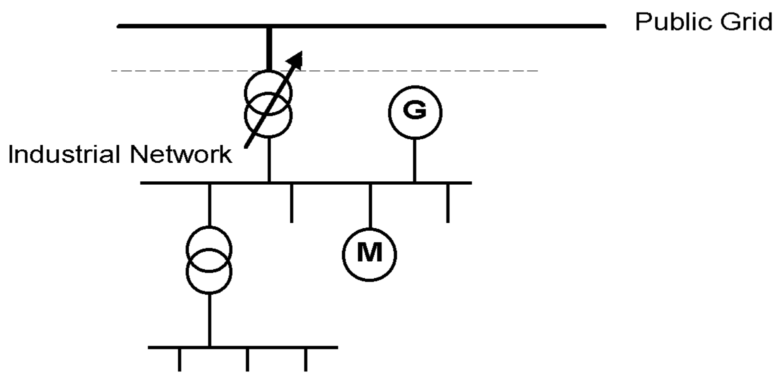
G(Generation)-Type Network: electrical network, self supporting, no coupling to the public network possible.

Figure 1 G-type network



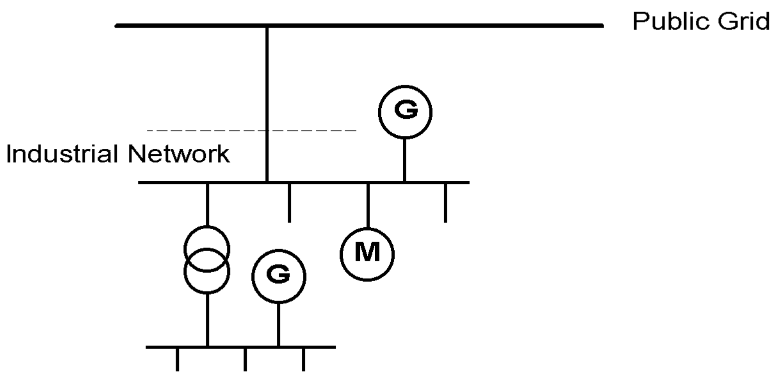
PGT(Public/Generation, Transformer connected)-Type Network: electrical network coupled to the local public network through transformer with on load tap changer, own generation in parallel.

Figure 2 PGT-type network



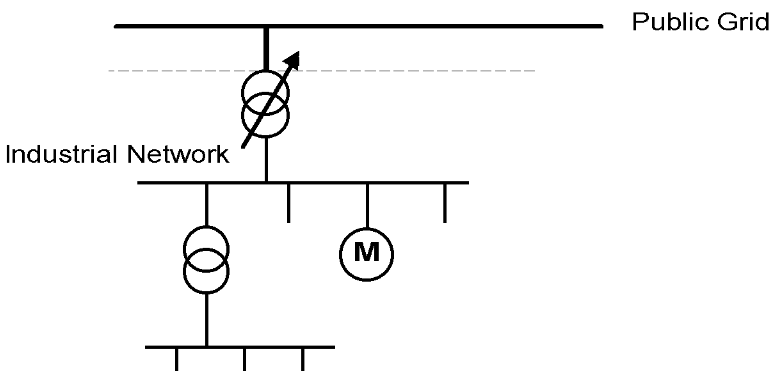
PGD(Public/Generation, Directly connected)-Type Network: electrical network coupled directly to the local public network, own generation in parallel.

Figure 3 PGD-type network



P(Public)-Type Network: electrical network coupled to the local public network, no own generation available.

Figure 4 P-type network



2.2.3 Control

The following definitions have been adapted for use in industrial plant grids and are slightly different to those in general use in public networks.

Primary control	control system that is directly related to the controlled device.
Secondary control	control system that is related to parallel operating devices having the same primary control function.
Tertiary control	control system that is related to the exchange of active or reactive power with an external network.

2.3 ABBREVIATIONS

ACO	Automatic Change Over
CCT	Critical Clearance Time
OLTC	On Line Tap Changer
PCC	Point of Common Coupling

3. CLASSIFICATION

3.1 GENERAL

The objective of classification is to identify equipment and its functions so that operation and design choices can be made. The classification is to be used only within this DEP and is not related to other standards or DEPs unless mentioned otherwise. Classification itself is not a reason for the choice of equipment or system lay-out; such choices are dictated by process constraints and technical and economic evaluations. Afterwards, a classification is performed to make choices on control and operations.

Classification is a means of discriminating between the functions and conditions of equipment and systems in relation to processes affecting their operation.

It is also used to identify the operational conditions of electrical systems, i.e. plant networks and external networks, in terms of voltages and frequency.

In this DEP such classification is applied to equipment that has a function in the control of voltage, power and frequency such as generators, prime movers and ties to an external network. The plant network configuration influences the control system and is also covered by the classification.

Appendix 1 shows two examples of carrying out such classifications for two typical networks.

3.2 OPERATIONAL CONDITIONS

The classification of operational conditions for a plant network or an external network is given in Table 1.

Table 1 Classification of operational conditions

Class.	Type	Voltage (per unit)	Frequency (per unit)	Description
OC1	Steady State	$0.95 \le U \le 1.05$	$0.98 \le f \le 1.02$	Normal operational conditions, equipment is able to perform all primary functions continuously
OC2	Sustained	$0.90 \le U < 0.95$ $1.05 < U \le 1.10$	$0.95 \le f < 0.98$ $1.02 < f \le 1.03$	Abnormal operational conditions without loss of generation or load
OC3	Deviated	$0.70 \le U < 0.90$	$0.92 \le f < 0.95$ $1.03 < f \le 1.10$	Transient conditions to be operated for a limited time span
OC4	Degenerated	$U < 0.70$		Loss of generation and load if cause is not eliminated immediately

Allowable deviation in supply voltage and frequency within a plant network shall comply with DEP 33.64.10.10-Gen. IEC 60034-1 forms the basis for the definition of classes OC1 and OC2.

Operational conditions other than OC1 shall be restricted in their duration.

Tap changer control shall partially compensate for any voltage deviations in an external network if the ties consist of transformers with on-load tap changers. The design will be such that if the voltage of the external network temporarily deviates within the limits of OC2, the plant network will be maintained in steady-state conditions (OC1).

Permanent frequency deviations in the external network are always passed on to the plant network and cannot generally be reduced by changes in the total amount of generated power within the plant grid.

Frequency fluctuations, however, depend on the ratio of load fluctuations to firm capacity.

3.3 GENERATING UNITS

The main design considerations are:

1. Does the generating unit constitute part of a process that restricts the capabilities of controlling the power output?
2. Is the generating unit able to sustain power supply during and after disturbances in the plant's process?

There are many types of generating units and plant process and so generating units are classified according to the degree to which the prime mover is independent of fuel supply and of the generation of process heat. The control of generating units, however, may also depend on other processes such as steam generation or on the lay-out, such as the presence of a bypass for exhaust gas. The classification is given in Table 2.

Table 2 Classification of generating units

Class.	Type	Capabilities
P1	**Fully independent** of process fuel supply, as it has own fuel supply or dual fuel capabilities. Power generation not restricted by another process such as heat generation.	Control of active power and frequency at the full range. Capable of operating as a power plant.
P2	**Partially process dependent** on fuel supply from plant process.	Active power and frequency control within restricted range imposed by upstream process.
P3	**Completely process dependent** on non-electric process such as heat generation.	Power generation completely controlled by another process.
P4	**Emergency** power supply completely independent	Control of active power and frequency over entire range. Able to start without any external electricity source.

The operational constraints of generating units depend not only on the availability of fuel or the process of heat generation, but possibly also on system layout. A combined cycle unit, for example, can only be operated without heat recovery if an outlet bypass is available.

3.4 GENERATORS

The main design consideration is whether the generator can withstand a fault current for the time needed by the protective device to isolate it. This will depend on the design of the excitation equipment. Further design considerations are given to the generator's ability to control voltage and reactive power. The classification is given in Table 3.

Table 3 Fault-current classification of generators

Class.	Type of equipment	Capabilities
G1	Synchronous generator with an independently powered excitation system	Automatic control of voltage and/or reactive power. Able to withstand a certain short circuit current during a fault.
G2	Synchronous generator with a dependently powered excitation system	Automatic control of voltage and/or reactive power. Not able to withstand a short circuit current.
G3	Asynchronous generator	Not able to control voltage or reactive power or to withstand a short circuit current.

The design of the excitation system shall be such that the synchronous generators will comply with classification G1 which is the preferred solution.

The excitation system including its control equipment shall have an independent power source. It shall remain unaffected by changes in the voltage of the network to which the generator is connected. The excitation system shall comply with DEP 33.65.11.31-Gen.

The excitation system shall enable a generator classified G1 to produce a terminal current of at least three times the rated value during three seconds under the operational conditions OC4.

3.5 PLANT NETWORKS

Classifying plant networks has the purpose of establishing whether more than one voltage level is present and whether more than one device able to control the same busbar voltage is connected to one or more of those levels.

If several devices are able to control the same busbar voltage, control functions shall be ranked in order of precedence to avoid uncertain and contradictory results.

The classification given in Table 4 shall also take account of whether generating capacity is located within the plant grid and/or beyond the point of common coupling to the external grid.

Table 4 Classification of plant networks

Class.	Type of network	Description
Q1	Single level voltage and reactive power control	All synchronous generators for continuous operation or other reactive power generating equipment are connected to the same busbar or busbars interconnected by cable feeders.
Q2	Multiple level voltage and reactive power control	Reactive power generation can be performed at different voltage levels that are connected by transformers with on-load tap changers.
Q3	No reactive power control	Voltage control is only possible by transformers with on-load tap changers.

NOTE: Multiple level is only assumed if the generating units are not class P4 or G3.

3.6 TIES

A tie is an interconnection between a plant network and an external network. The interconnection may consist of:

1. overhead lines;
2. underground cables;
3. transformers.

The purpose of classifying ties is to determine the strength of the interconnection, which depends on:

1. the power supply capabilities of an external network in relation to the generating capacity of the plants;
2. the short circuit contribution in relation to the short circuit contribution of the generating units, which is a measure of voltage support.

If the tie to a plant network consists of transformers, it shall be equipped with on-load tap changers.

3.6.1 Power supply capabilities

Plant network ties are classified according to their power supply capabilities as shown in Table 5. The redundancy of the ties shall be considered in assigning a classification.

Table 5 Classification of power supply capabilities of a tie

Class.	Power Supply	Conditions
PS1	Full support	Capable of supplying the total load of a plant network and of exporting the total generated power.
PS2	Load support	Capable of supplying total load of a plant network but not of exporting the total generated power. Generated power is in excess of load.
PS3	Generation support	Capable of exporting the total generated power but not of supplying the total load of a plant network. Load is in excess of generated power.
PS4	Partial support	Not capable of supplying the total load of a plant network or of exporting the total generated power.

The assumption here is that it is not the external network but only the interconnection that is the constraining factor. In some cases, however, the ratings of other ties within the external or the plant network may impose constraints. This shall be investigated and recorded.

3.6.2 Short circuit contribution

A tie can be further classified by its short circuit contribution in order to determine its contribution to voltage stability. Its contribution will always be related to that of the synchronous generating units and the synchronous motors. In the evaluation only the short circuit contribution of the external network and the subtransient short circuit currents of synchronous generators and motors shall be taken into account. For this classification only, the short circuit contribution of other devices such as asynchronous machines shall be ignored because they are unable to control the reactive power output. The classification is given in Table 6.

Table 6 Classification of short circuit contribution of a tie

Class.	Strength	Contribution of external network
SC1	strong	$S_k'' \geq 60\%$, changes in reactive power exchange have a limited effect on the voltage.
SC2	intermediate	$40\% \leq S_k'' \leq 60\%$, changes in reactive power exchange have an effect on the voltage.
SC3	weak	$S_k'' \leq 40\%$, changes in reactive power exchange have a strong effect on the voltage.

As a consequence of this classification, plant networks without generating capacity will always have a strong tie.

3.7 EXTERNAL NETWORK

The quality of the power supply from medium voltage networks may be reviewed with the aid of EN 50160. Classifying an external network has the purpose of determining its availability. The main consideration is the reliability of the power supply from the external network in comparison with power generation within the plant network and in relation to the vulnerability of the plant process to disturbances in the power supply.

The following questions have to be answered:

1. which part of the power supply will be procured from an external network?
2. will operation as an electrical island be a viable option (6.4)?

If the reliability of the plant's own power generation exceeds that of the external network by a substantial factor, appropriate measures shall be taken to protect against disturbance by external failures. If the opposite is true, the connection to the external network may improve the reliability of the power supply and should be maintained for as long as possible.

In assessing the external network, a distinction shall be made between interruptions of the power supply and short voltage dips. There is no sharp borderline laid down in international standards between power failures and voltage dips and so this distintion shall be based on the effects on the plant process. In the evaluation of the consequences of any power supply interruption or voltage dips caused by failures in the external grid, the following factors shall be considered:

1. Regarding the disturbance itself:
   - the number of events per annum;
   - the duration of each event;
   - the amplitude of the voltage depressions.
2. Regarding the plant:
   - the effects on the generating units in terms of technical and economic losses and the restarting time needed;
   - the technical effects on loads in terms of loss of load and restarting of motors;
   - the economic effects in terms of loss of production and restarting costs.

3.7.1 Interruption of power supply

In the special case of industrial plants, an interruption of the power supply may be characterised as a voltage depression with a duration of more than one second with a residual voltage of less than 70% of the rated value. The availability of the power supply shall be calculated from the following two variables:

- the number of interruptions per annum expressed as the mean time between failures (MTBF) in years;
- the average duration of the interruption expressed as the mean time to repair (MTTR) in hours. In this particular case this equals the average time needed to restore the power supply.

From both variables (MTBF and MTTR) the availability or non-availability of the external grid in hours per year may be calculated.

The availability A is given by

$$A = \frac{MTBF}{MTBF + MTTR}$$

and the non-availability U is given by

$$U = 1 - A = \frac{MTTR}{MTBF + MTTR}$$

When evaluating the availability of the power supply, the technical and economic effects of an interruption on the plant process shall be reviewed. The key criterion is not the restoration of the power supply itself but the restoration of the plant process to the required specifications. The MTTR characterising the non-availability of the plant process caused by interruptions of the power supply may be taken for that purpose.

3.7.2 Voltage dips

In conformity with IEC 61000-4-11 a voltage dip is defined as a sudden voltage depression followed by a recovery after a short period of time. In industrial plants, a voltage dip may be characterised as a voltage depression with a duration of one second or less for any residual voltage or for a longer duration with a residual voltage greater than 70%. For the purpose of statistical analysis voltage dips may be classified according to Table 7 in any combination of duration and residual voltage resulting in a total of 16 combinations. Table 7 is a simplification of a similar table given in IEC 61000-4-11 and more suitable for industrial plants. Further simplification may be made if fully justified.

Table 7 Classification of voltage dips

Residual voltage	[%]	U ≤ 1	1 < U ≤40	40 < U ≤70	70 <U ≤90
Duration	[ms]	10 < t ≤ 100	100 < t ≤ 500	100 < t ≤ 500	500 < t ≤ 1000

The classification of the time duration may be aligned with the settings of relevant protective devices in the external grid.

3.8 SUMMARY

Not all the classifications given in the previous section are applicable to all the different types of generating units and plant networks. Tables 8 and 9 give an overview.

Table 8 Applicability of classifications to generator types

Generator	OC	P	Q	PS	SC
G1-type	+	+	+	+	+
G2-type	+	+	+	+	+
G3-type	+	-	-	-	-

Table 9 Applicability of classifications to network types

Network	OC	G	P	Q	PS	SC
G-type	+	+	+	+	-	-
PGT-type	+	+	+	+	+	+
PGD-type	+	+	+	+	+	+
P-type	+	-	-	-	-	-

4. POWER AND FREQUENCY CONTROL

4.1 GENERAL

In this DEP the control of frequency and power is related to generating units only. The controlling action is applied to the prime mover of the generating unit. The objectives of such control depend on the nature of the network:

1. If the plant network is connected to an external network, frequency is dictated by the latter network. The objective(s) will then be:
   - to control the electrical output of the generators in operation;
   - optionally, to control the power balance between generators;
   - optionally, to control the export and import of electrical power.
2. If the plant network is operated in island, electrical power output is dictated by the load. The objectives will then be:
   - to maintain frequency within a certain bandwidth;
   - to maintain a balance in the active power output between all generators in operation.

The definition and ranking of control functions, irrespective of the layout or function of the control system, is given in table 10. Primary control shall have the fastest response, followed by the secondary control. Tertiary control shall be the slowest.

Table 10 Definitions of power control functions

Ranking	Function
Primary	Control of frequency and/or electrical output power of a single unit
Secondary	Control of power sharing among several units
Tertiary	Control of power exchange to an external network

In some cases, output power is not regulated. This is only possible if that particular unit is running in parallel with an external network or other units to absorb load changes.

4.2 FUNCTIONAL REQUIREMENTS

Different types of frequency and power control system with different modes of operation can be distinguished.

4.2.1 Process control

This applies to generating units classified as P3. The power output of the prime movers is connected to another process such as steam generation, e.g. in back pressure steam turbines where the steam supply and other process parameters define the amount of electrical power. The electrical output is controlled indirectly. Such a configuration shall only be employed if other synchronising sources of sufficient capacity are available. These sources may be a connection to an external network or other generating units with frequency and power control.

Gas turbines are often operated at the limit of the exhaust gas temperature. The control system is fully operational but there is no capacity for power increase. This limits the actual function of the frequency control system.

4.2.2 Frequency control

A frequency control system shall be designed to maintain the frequency within a narrow bandwidth. There are two modes of frequency control:

1. *Isochronous control*:
   Frequency is maintained exactly at the frequency set point within the full power range. In practice it is impossible to have two generating units running in parallel with the same set point. Moreover, the frequency in a public network will fluctuate. As a consequence isochronous control shall at the very most be used on a single generating unit in a G-type network. All changes in load will be intercepted by that particular generator.

Secondary power control shall continuously adjust the output power of the remaining generating units.

2. *Droop control*:
   Frequency decreases along a fixed slope over the full power range. This will counteract output power swings caused by frequency fluctuations. The percentage droop indicates the change in frequency between no load and full load. The control action with the steepest slope will exhibit the smallest power fluctuations. With network connected operation the unit with the lowest droop value will initially exhibit the greatest power changes induced by frequency changes. In island operation the unit with the lowest droop value will intercept most of the power changes. Frequency is adjusted by changing the reference frequency value of one or more generators. Secondary control has to maintain power sharing between generators.

The effect of frequency control depends on the operational condition:

1. In a PG-type network frequency is enforced by the external network. As none of the generating units is able to influence the frequency, an increase in the frequency set point will lead to an increase in output power. In this configuration frequency control can be used indirectly as power control.
2. In a G-type network, an increase of one unit's frequency control set point will lead to:
   - if all units have the same droop, an increase of output power at the expense of the other units while the frequency will increase;
   - if the unit is on isochronous control and other units are on droop control, the frequency will increase and the power output of all other units will decrease at the expense of the isochronous unit;
   - if the unit is on droop control and there is one unit on isochronous control, the frequency will not change and the power output of the unit will increase at the expense of the isochronous unit;
   - if the unit is on droop control and there are units with a different droop, the frequency will increase and the power output of the unit will increase at the expense of the other units. The units with the smallest droop setting will contribute most to the power decrease.

Generating units classified as P1 and P4 shall have the ability to operate on isochronous and droop control modes. Units classified as P2 shall be able to operate on droop control mode and units classified as P3 may have optional droop control.

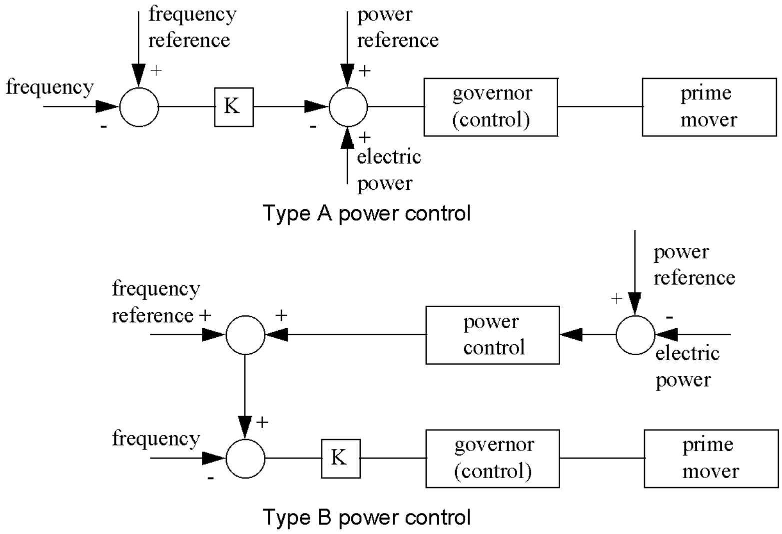
4.2.3 Power control

Electrical power is maintained at a fixed value. This type of control is only suitable if other sources (external network, other generating units) offset load changes. The power control acts much in the same way as droop control, but its dynamic behaviour is different. Output power can be controlled in two ways:

1. As a primary control system incorporated in the frequency control. In this case the control system will maintain the output power constant while allowing some droop. The power control acts as fast as the frequency control and may be sensitive to disturbances from the network.
2. As a secondary control system that acts upon the frequency control set point (Figure 5). The power control has to be much slower than the frequency control.

Each power control system shall provide stable operation during both island operation and parallel operation with an external network. Island operation shall be stable regardless of the actual type of plant network. Power control mode is optional for type P1 generating units. The preferred solution is the type B control configuration.

Figure 5 Preferred electric power control



4.2.4 Preferred functions

Table 11 gives an overview of the preferred frequency and power control functions to be installed according to the classification of generating units (3.3) and regardless of the type of interconnection.

Table 11 Preferred frequency and power control functions to be installed

Class.	Primary	Secondary	Tertiary
P1	Frequency control with isochronous and droop setting	Mutual power sharing	Power exchange to external network
P2	Frequency control with droop setting	Individual control process dependant	Optional
P3	Output power process dependent	Not applicable	Not applicable
P4	Frequency control with droop setting	Mutual power sharing	Not applicable

Within the frequency control system a dead band shall be applied to eliminate continuous control actions without affecting the stability of the control system. Its width shall be adapted to the continuous frequency oscillations from the external grid or from the switching of loads. The minimum value shall be 20 mHz for the primary control. Droop setting shall not be affected by the dead band setting. Unless agreed otherwise, the dead band for the active power within the tertiary control shall be large enough to minimise control actions.

Units classified as P1 and P2 shall have secondary control. All units classified as P1 shall have an interconnected secondary control.

Tertiary control shall only be implemented under technical or financial agreements with the administrator of the external network. It shall also be implemented where there is interchange between generating areas.

4.3 OPERATIONAL REQUIREMENTS

The required frequency and power control functions depend on the power supply capabilities of the ties and external network. For the different types of industrial networks and interconnections the same definitions taken from DEP 33.64.10.32-Gen, as further qualified in (2), will apply.

The principle of frequency and power control may be stated as follows:

1. The source with the largest power supply capabilities shall control the frequency. For PGT and PGD-type networks, this is in generally the external network regardless of the capacity of the ties. For G-type networks, such a source may consist of one or several generating units. These frequency controlling sources shall have secondary control to maintain the desired power sharing.
2. The output power of all other available sources shall be controlled individually to obtain the desired contribution to the power supply.

4.3.1 Generation type plant network

The frequency control system shall maintain the frequency within a bandwidth of 2% under steady state conditions.

As the plant network is operated continuously (or even temporarily) as an electrical island, only a single generating unit classified as P1 shall operate on isochronous mode and all other generators classified as P1 and P2 shall operate on frequency control with droop setting. The unit operating on isochronous mode shall have the highest power rating.

The reaction time of the secondary control of class P2 units is process-dependent.

All units classified as P1 shall operate within an interconnected secondary control system.

4.3.2 PGT and PGD-type plant networks

All generating units shall operate stably within the frequency ranges classified as OC1 and OC2.

During operation as PG-type networks, units classified as P1 shall operate on droop control mode.

Tertiary control will only be implemented on class P1 generating units. Control functions shall depend on the power supply capabilities of the ties:

1. *Type PS1- tie*: There are no limitations on the power exchange. Tertiary control is optional and shall only be implemented if an agreement with the administrator of the external network makes it necessary to do so.
2. *Type PS2- tie*: There are limitations on the power export. Tertiary control shall be implemented if there is a risk of overloading the ties by a generation surplus.
3. *Type PS3- tie*: There are limitations on the power import. Tertiary control is optional and shall only be implemented if an agreement with the administrator of the external network makes it necessary to do so.
4. *Type PS4- tie*: There are limitations on the power exchange. Tertiary control shall be implemented.

5. VOLTAGE AND REACTIVE POWER CONTROL

5.1 GENERAL

This section presents a guideline for the design of a voltage and reactive power control system. The implementation of the control system depends not only on the equipment available for controlling these variables, but also on the layout of the plant network and the interconnection with an external network.

The choice of equipment for controlling voltage and reactive power shall be initially based on the equipment available and on DEP 33.64.10.10-Gen. Table 12 gives an overview of equipment and its ability to control voltage and reactive power.

Table 12 Voltage controlling equipment

Equipment	Main function	Additional functions
Transformer with on load tap changers	Control voltage at the busbar	None
Synchronous generators and motors	Control voltage at the terminals or busbar	Control reactive power exchange with an external network
Capacitor banks	Improve power factor	Increase voltage at the busbar

A distinction should be made between voltage and reactive power control:

1. Voltage control: the control system will maintain the voltage constant within a certain bandwidth. This primary function will be allocated to transformers with on-load tap changers, synchronous generators and synchronous motors. The latter two have a faster response then the first and give the best contribution to voltage stability when loads are switched on and off.
2. Reactive power control: the control system is superimposed on the voltage control and has a slower response. If two or more generators are running in parallel, this secondary function is always necessary to keep a balanced distribution between the generators in operation.

Because of the network impedances, an increase of the generator's reactive power output will lead to an increase of the terminal voltage. This is the natural droop of the system. Besides this natural droop, a voltage control system may have an adjustable droop setting. This droop setting may be proportional to the active and reactive power outputs. In the latter case this is sometimes called "quadrature droop". In this section droop is designated in relation to AVRs (Automatic Voltage Regulators).

The order of preference for controlling voltage and/or reactive power from high (1) to low (4) is as follows:

1. transformers with on load tap changers and/or synchronous generators;
2. synchronous motors only if available;
3. fixed shunt capacitor banks;
4. thyristor controlled static VAR compensators.

5.2 TYPES OF CONTROL

Voltage control will be a primary function and shall be used to maintain one or more busbar voltages in a plant network within narrow fixed limits under normal operational conditions. The bandwidth shall be such that the allowable voltage deviations within the plant network will comply with DEP 33.64.10.10-Gen.

Reactive power control is a secondary and tertiary function and shall be used:

1. As a secondary function to maintain generators within the operational limits. This function may be extended to provide a constant reactive power output or a constant power factor.
2. As a tertiary function to maintain the exchange of reactive power with an external network within a certain bandwidth or to provide a constant power factor to the power exchange. Tertiary control will lead to an overall system power factor improvement and shall comply with DEP 33.64.10.10-Gen.

Primary, secondary and tertiary control functions shall be hierarchically separated within a control system. As the three functions will influence each other, stable operation can only be enforced by a distinction in time response. The time responses of the primary, secondary and tertiary control system shall be such that stable operation is guaranteed for all operational conditions. Primary control shall act fastest and tertiary control shall act slowest.

Secondary and tertiary control shall allow for the operational constraints of the controlled device.

One or more control functions will be assigned to equipment in relation to its capabilities and to the lay out of the electrical infrastructure. Table 13 gives an overview of the most common control functions and the related equipment.

Table 13 Assignment of control function to equipment

Equipment	Control functions		
	Primary	Secondary	Tertiary
Transformer with on load tap changers	Voltage control at busbar	Synchronisation of tap position for parallel operation	
Synchronous generators	Voltage control at terminals or busbar	Control of reactive power distribution between several generators	Control of reactive power exchange with an external network
Shunt capacitors	Power factor improvement of loads		Control of reactive power exchange with an external network

If identical devices control the voltage at the same busbar, at least a secondary control function shall be part of the control system. The secondary control function may be implemented as droop control to maintain the reactive power balance between parallel generators.

If a transformer and a synchronous generator both control the voltage at the same busbar, conflicting control action may arise. This will generally be avoided by:

1. assigning the voltage control function to the tap changer;
2. having sufficient droop setting at the generator voltage control;
3. incorporating a secondary control function in the excitation control system. Nevertheless the primary control of the generator will remain functional to guarantee stability. If more generators are in service a tertiary control may be added.

5.3 FUNCTIONAL REQUIREMENTS

The required functions for voltage and reactive power control depend on the electrical infrastructure, the ties and the external network. For the different types of industrial networks and the interconnections the same definitions taken from DEP 33.64.10.32-Gen, as further qualified in (2), will apply.

Although the electrical infrastructure may vary, the principle of voltage control may be stated as follows:

1. The source with the highest short circuit power shall first control the voltage;
2. All other available and suitable sources including the foregoing will be used to obtain the desired contribution to reactive power supply.

Most equipment items have different control functions. Table 14 gives an overview.

Table 14 Control functions and remarks

Equipment	Control	Function	Remarks
Tap changer control system of transformers	Primary	Maintain voltage at the regulated side	To compensate for voltage deviations at the non regulated side or loading changes.
	Secondary	Assure synchronised tapping of parallel transformers	Always necessary with parallel operation of transformers.
	Tertiary	If the transformer forms a tie, to adjust reactive power flow through it	Only recommended in special cases. Only feasible in combination with synchronous generators that have only primary control.
Excitation control system of synchronous generators and motors	Primary	1- Adjust terminal voltage to a definite value 2- Ensure sufficient fault currents 3- Maintain stability of the synchronous generator	Because of the multiple functions, voltage control is indispensable.
	Secondary	Ensure a balanced distri-bution of reactive power between several generators, or ensure a fixed power factor of the generator	Control will act on set point of primary control.
	Tertiary	Improve power factor of the power exchange to a desired value	Control will act on secondary control.
Control system of shunt capacitor banks	Primary	Power factor improvement of loads	Essentially not a control function, implemented as fixed capacitors.
		Control busbar voltage	Not to be implemented in parallel with tap changer control or synchronous generators and motors.
	Secondary	Logic for the selection of the bank to be switched	Applicable to multiple parallel banks.
	Tertiary	Reduce total reactive power loading from an external network	Function may be implemented without primary control for capacitor banks.

Generation by class P4 units shall be excluded from tertiary control and shall have a class G1 generator.

The exchange of reactive power with an external network shall be limited. Unless there are special agreements with the administrator of the external network, power factor shall be held between 0.80 and 1.0 for import and to 1.0 for export.

If only a single generator is in service, secondary control may be replaced by tertiary control.

As the requirements depend on the type of plant network, they are classified accordingly.

5.3.1 Generation type plant network

As the plant network is operated continuously (or even temporarily) as an electrical island, voltage control will be assigned to the generators connected to the main busbar. The voltage control system has the capability of droop setting and shall be designed to maintain the voltage within 0.5% of the operational value during normal operational conditions. A secondary control system will maintain the reactive power distribution between the generators in operation by adjustment of the AVR set point. This is applicable to all island operated networks.

At least part of the generating capacity intended for continuous operation shall be connected to the main busbar.

If all generating capacity is connected to the same busbar the control system can be limited to:

1. primary voltage control of the main busbar by all generators in operation;
2. secondary control system to maintain a balanced sharing of reactive power between all generators in operation. If only a single generator is in service, generator voltage control shall suffice.

5.3.1.1 Generation at a second level

If additional power is generated at a lower voltage level the option shall be studied of having on-load tap changers at the interconnecting transformers to limit voltage deviations. The assessment shall be based on the voltage deviations between minimum and maximum transformer loadings and voltage fluctuations caused by tripping of generators and switching of loads, taking into account the maximum allowable voltage deviations (OC1).

The function of voltage control will be primarily assigned to equipment connected to the main busbar as stated in the previous paragraph. The additional control system governing lower-level generation shall include:

1. Primary control of the lower busbar by the tap changer of the feeding transformers for sustained operational conditions (OC1) at the main busbar. As generators will also control the voltage, the effect of the tap changer on the busbar voltage may be limited. For this reason sequential stepping may be limited.
2. Primary control of all synchronous generators feeding the lower busbar, with appropriate reactive power droop setting
3. Secondary control of reactive power or power factor of all generators connected to the second level. Power factor control shall be related to secondary control of the generators at the main busbar. If only a single generator is in service, generator voltage control with droop setting will be sufficient.

Within the secondary control system of the main busbar, any generating capacity at a lower voltage level may be regarded as a single generator.

5.3.2 PGT type plant network

Without control actions, the voltage of the main busbar will in most cases follow all voltage changes in the external network. These changes will induce undesirable reactive power flows through the interconnecting transformers which can be overcome by appropriate secondary and tertiary control systems. Primary control of the voltage at the main busbar will be assigned to the tap changer of the interconnecting transformer. The voltage control system has to be designed to maintain the voltage at the main busbar within 2% of the nominal value during sustained and deviated operational conditions (OC1 and OC2) of the external network.

With all generating capacity connected to the main busbar, control shall be based on the following design, provided the interconnection is classified SC1 or SC2:

1. Primary voltage control of the main busbar by the tap changer of the interconnecting transformers for operational conditions OC1 and OC2 at the external network.
2. Primary control of all synchronous generators connected to the main busbar, with appropriate reactive power droop setting.
3. Secondary control of reactive power or power factor of all generators by adjustment of the AVR set point. If only a single generator is in service, generator voltage control with droop setting will be sufficient.
4. Tertiary control of the power factor of the power exchange by changing the generator's reactive power output.

With a weak interconnection classified SC3 the voltage control capability of the interconnecting transformers is limited. This function shall then be assigned to the generators. The tap changer shall be adjusted to limit the reactive power exchange caused by voltage variations in the external network or alternatively the reactive power control system shall be designed to maintain a fixed reactive power exchange or a fixed power factor. The control functions will be:

1. Primary control of all synchronous generators connected to the main busbar, with appropriate reactive power droop setting.
2. Secondary control of reactive power or power factor of all generators by adjustment of the AVR set point. If only a single generator is in service, generator voltage control with droop setting will be sufficient.
3. Tertiary control of the power factor of the power exchange by the tap changer of the interconnecting transformer.

5.3.2.1 Generation at a second level

If additional power is generated at a lower voltage level the alternative option as described under (5.3.1.1) shall be studied.

The function of voltage control will be primarily assigned to equipment connected to the main busbar as stated in the previous paragraph. The additional control system governing the generating capacity at lower level shall include:

1. Primary control of the lower busbar by the tap changer of the feeding transformers for sustained operational conditions (OC1) at the main busbar.
2. Primary control of all synchronous generators feeding the lower busbar, with appropriate reactive power droop setting,
3. Secondary control of reactive power or power factor of all generators connected to the second level. Power factor control shall be related to secondary control at the main busbar. If only a single generator is in service, generator voltage control with droop setting will be sufficient.

As generators at the lower voltage level will also control the voltage, the effect of the tap changer on the busbar may be limited in the case of a weak interconnection. For this reason the speed of sequential stepping of the tap changer may have to be limited by an appropriate time interval.

Within the secondary and tertiary control systems of the main busbar, any generating capacity at a lower voltage level may be regarded as a single generator.

5.3.3 PGD-type plant network

In this case the voltage of the main busbar will always follow the voltage fluctuations of the external network. This will introduce changes in the reactive power output of the generators which has to be corrected by the tertiary control.

The control functions for this type of network will be identical to points 2, 3 and 4 of the PGT-type of network (5.3.2) with the exception of the case where a single generator is connected to the main busbar. In that case the single generator shall be equipped with a power factor control, and tertiary control is optional.

The voltage control and reactive power control shall be based on the following design:

1. Primary control of all synchronous generators connected to the main busbar, with appropriate reactive power droop setting.
2. Secondary control of reactive power or power factor of all generators by adjustment of the AVR set point even if only a single generator is in service.
3. Tertiary control of the power factor of the power exchange.

If additional power is generated at a lower voltage level, the control functions at that level will correspond to the PGT-type network (5.3.2.1).

5.3.4 Public type network

A transformer with OLTC feeding the plant network will obviously be the sole possibility of controlling the voltage at the main busbar.

An assessment shall be made of the economic and technical benefits of incorporating on-load tap changers on the interconnecting transformer. It will be based on:

1. the voltage deviations in the public network;
2. the allowable voltage deviations in the plant network;
3. the maximum allowable transformer loading.

The voltage control system shall maintain the voltage in the plant network within the limits given by the operational conditions OC1 for voltage deviations corresponding to OC1 and OC2 in the external network.

During normal operating conditions the voltage at the main busbar will be controlled within an accuracy of 2%.

5.4 EQUIPMENT

5.4.1 Transformers with on-load tap changers

Power transformers shall be designed in accordance with DEP 33.65.40.31-Gen. Additionally, with the exception of step-down transformers, the primary control system will be designed to maintain the secondary voltage within a certain bandwidth to compensate for:

a) voltage fluctuations at the primary side;
b) changes in voltage drop at the secondary side caused by fluctuations in the transformer loading.

A secondary control system shall maintain the correct tap position of parallel transformers to eliminate circulating reactive currents.

Continuous stepping of the tap changer will increase the necessary maintenance and reduces the life time. For these reason it has to be avoided by:

1. setting a voltage range (bandwidth) between the maximum and minimum reference voltage of at least 150% of a single step voltage increment and by
2. introducing a time delay ranging from 10 seconds up to several minutes. This time delay may be automatically decreased if the voltage deviation exceeds a second bandwidth setting.

The tap changer and its control system shall be able to maintain the regulated voltage within ± 2% of the nominal value.

5.4.2 Synchronous machines

Synchronous generators and motors are able to control the terminal voltage as well as the reactive power output. Therefore each synchronous machine has to be equipped with an excitation system and its control. Synchronous generators and excitation systems shall comply with DEP 33.65.11.31-Gen irrespective of the following paragraphs. The excitation system has several main functions:

A. Adjust the voltage to a definite value. The voltage may be kept nearly constant over the entire power range. In general, however, it is desirable to introduce some droop, which may depend on active and/or reactive power output. Positive droop introduces the possibility of compensating for the voltage drop across external impedances. Negative droop setting is always necessary for generators running in parallel with little or no impedance in between to create an artificial coupling impedance.

B. Maintain the dynamic stability of the synchronous machines. The stability depends on the type and settings of the excitation control system. The settings shall be adjusted by the Contractor during commissioning and reported to the Principal.

C. Ensure sufficient continuous output current during electrical faults. The level of fault current depends mainly on the exciter ceiling voltage in relation to generator impedances. The fault current shall amount to approximately $3*I_n$ and should stand long enough for protective devices to work appropriately.

The voltage is the predominantly controlled quantity which is handled by primary control. Secondary control acts on the voltage control set point and regulates the reactive power output to:

1. Keep the power factor of a synchronous machine constant. This is only relevant if other sources such as an external network or other synchronous machines can supply the variance in reactive power.
2. Adjust the sharing of reactive power between the generators running in parallel. This function is indispensable and shall be performed automatically.

The exchange of reactive power with an external network will mostly be subject to contract agreements. In that case a tertiary control shall be provided to automatically adjust the reactive power exchange as agreed.

The time response of the primary function of the excitation system is very fast, ranging from less than one second to several seconds. The time response of the secondary functions has to be slower than that of the primary control and will range from ten seconds up to several minutes to avoid conflicting control actions. For the same reasons tertiary control has to be slower than secondary control.

5.4.2.1 Excitation systems

The primary function of the excitation system is to provide the field current required by the synchronous machine so that a specific range of operating conditions can be met. The behaviour of the generator in terms of voltage and reactive power control, stability and short-circuit characteristics depends greatly on the design of the excitation system.

The excitation system and its control shall comply with DEP 33.65.11.31-Gen and DEP 33.64.10.10-Gen unless explicitly stated otherwise.

The excitation system and its control shall be able to operate regardless of the operational conditions. This means that its function shall be independent of the power supply capabilities of the network, the auxiliaries and the generator terminal voltage.

The preferred solutions for excitation systems stem from to the three ways of achieving this independence. They are given in the order of preference:

1. *Permanent magnet pilot exciter with brushless AC main exciter and rotating rectifier*
   The power supply to the control system shall be taken from the pilot exciter to guarantee independence of the generator terminal voltage and auxiliaries. The PM pilot exciter forms the independent power source to the main exciter and the excitation control system.
2. *Brushless AC main exciter and rotating rectifier*
   The power supply to the excitation system may be taken from:
   - a compound source from the generator terminals to supply the main exciter after rectification. The source consists of voltage and current transformers to make the supply independent of the terminal voltage. The system is self exciting. The excitation control system shall be supplied from a separate uninterruptible power source taken from the generator's auxiliaries.
   - Any other uninterruptible supply source from the auxiliaries of the generator.

Some gas turbine generator units make use of the synchronous generator as a variable speed drive for starting up. In that case the field excitation has to operate at very low speeds which makes rotating exciters and brushless excitation systems impracticable. The preferred solution in this particular case is a synchronous generator with slip rings and a compound source (voltage and current transformers) taken from the generator terminals. The excitation control system shall be fed from a separate uninterruptible power source taken from the generator's auxiliaries.

5.4.2.2 Data

Manufacturer/Supplier shall provide all data of generator and excitation systems necessary to perform stability studies. The data shall include the parameters as set during commissioning of the unit.

5.4.3 Shunt capacitor banks

The design and use of capacitor banks for power factor correction shall comply with DEP 33.64.10.10-Gen.

The main purpose of shunt capacitor banks is to improve the power factor of the load. The reason for this improvement may be:

1. Improve the power factor of an individual load.
2. Improve the power factor of the total load drawn from an external network in accordance with the agreements with the public network authorities.
3. Compensate the voltage drop caused by reactive power flow through a relatively weak connection.

Capacitor banks should only be used if on-load tap changers or synchronous generators or motors are not available or the rating of already installed equipment is insufficient to fulfil the required function.

A capacitor bank may consist of several units which can be switched on and off independently by the control system. The allowable voltage disturbance caused by the switching determines the maximum rating of a single unit. To avoid switching problems a continuously acting thyristor controlled capacitor bank may be used.

The maximum instantaneous voltage change caused by the switching of a single capacitor bank shall be 5%.

Multiple capacitor banks having a tertiary control function shall be switched sequentially. The time interval shall be long enough to allow complete adjustment of the busbar voltage by the primary control between two switching sequences.

Capacitor banks shall not have the primary function of voltage control in parallel with transformers with OLTCs or synchronous generators or synchronous motors.

6. DESIGN AND OPERATION

6.1 GENERAL

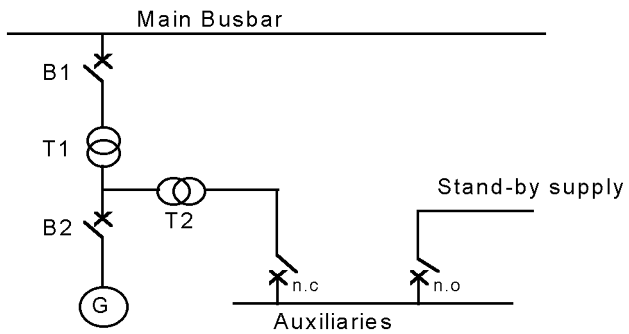
The design and operation of electrical systems shall comply with DEP 33.64.10.10-Gen in addition to the features addressed in this section.

6.2 GENERATING UNITS

The design and operation of generating units shall be directed towards safeguarding the power supply for as long as possible in the event of disturbances in the electrical system.

The preferred layout of the primary circuit for class P1 generating units is given in Figure 6. It enables the whole unit to be run in a small electrical island. Additionally the voltage of the auxiliaries may be kept at a higher level by the generator during voltage dips at the main busbar. Synchronisation shall be implemented on both breakers B1 and B2. T1, T2 and B2 shall be interconnected as a fixed busbar system or as a switchboard depending on voltage levels and economic and technical benefits. Breaker B2 will be open during the start up of the auxiliaries before synchronisation.

Figure 6 Preferred connection of class P1 generating units

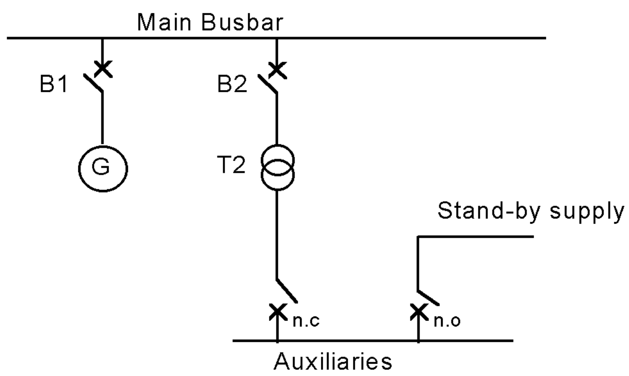


The auxiliary switchboard shall be treated as an essential services switchboard in accordance with DEP 33.64.10.10-Gen.

When the rated generator voltage and the busbar voltage are matched, the supply to the auxiliaries shall be taken from the main busbar according to Figure 7.

Generating units classified as P2 and P3 may have their auxiliary supply connected to another plant switchboard that is classified as an essential services switchboard.

Figure 7 Alternative connection of class P1 generating units



6.2.1 Auxiliaries

Auxiliaries are classified as essential consumers in accordance with DEP 33.64.10.10-Gen and shall be able to operate under deteriorated operational conditions. The main busbar to which the generator is connected shall be taken as the reference value for fixing the voltage of the operational conditions.

For steady state conditions classified as OC1, the auxiliaries shall be able to operate continuously and the generator will be able to run at rated output power and power factor.

For sustained conditions classified as OC2, the auxiliaries shall be able to operate continuously for at least 30 minutes and the generator will be able to run at rated output power and power factor. As these conditions comply with zone B of IEC 60034-1, extended operation in this zone is not recommended.

For deviated conditions classified as OC3, the auxiliaries shall be able to operate for at least 1 minute and the generator will be able to run at 50% of rated output power. These conditions comply with the permissible occasional excess current (1.5 times the rated current for at least 2 minutes) for low voltage AC motors ($P < 315$ kW) as stated in IEC 60034-1.

For degenerated conditions classified as OC4, the auxiliaries shall be able to withstand the voltage deviation for one second without the generator tripping. After voltage recovery above 95%, output power will be restored within 5 seconds.

In the assessment of operational conditions the ability of the standby supply to maintain voltage and frequency at a higher level than the main busbar may be taken into account. This also includes the effect of OLTCs for operational conditions OC1 and OC2 as wel as the switching of an ACO.

6.2.2 Spinning reserve

Spinning reserve has the objective of safeguarding the power supply after the tripping of a generator by maintaining a sufficient power control range at the generating units in service.

To be of practical use the spinning reserve has to be:

1. sufficient to set off the generator trip. If combined with load shedding, the spinning reserve required may be reduced
2. available very quickly by increasing the power output of the generator. The rate of change of the power output of the generating unit shall be high enough to make beneficial use of the spinning reserve. The maximum attainable rate of change depends on the type of prime mover. If the prime mover cannot fully cope, the frequency drop may be reduced by temporary load shedding.

An assessment shall be made of the economic and technical benefits of maintaining spinning reserve. Spinning reserve and cold stand by shall be evaluated on the basis of:

- the number and duration of unplanned outages and the availability of the generating units and the external grid (6.6);
- the installed capacity and investment costs;
- efficiencies and fuel costs;
- load shedding, production loss and starting-up time;
- maintenance;
- the capacity of ties in PGT and PGD-type networks;
- load shedding versus the necessary rate of change of prime mover power output for G-type networks.

The possible spinning reserve of type P3 generating units shall not be taken into account.

Spinning reserve is always relevant in G-type networks. To maintain the frequency at the operational conditions OC1 and OC2 when a generator trips, combined load shedding and spinning reserve (see DEP 33.64.10.10-Gen) shall be considered.

In a PGT and PGD-type network, spinning reserve may be an option if agreed with the administrator of the external network. On a temporary basis it may be an option to avoid overloading of the ties if tertiary control is part of the power control system.

6.2.3 Critical clearance time

The maximum time period during which a certain voltage drop may last without pole slipping after recovery of the voltage is determined by the critical clearance time (CCT). The CCT depends on many variables and also on the operational condition just before fault initiation. Therefore the CCT shall be calculated at the rated power and power factor of the generating unit at the normal operational voltage. The CCT increases with the residual voltage. Above approximately 50 to 60%, the generator can supply its power permanently to the network and the CCT is in principle infinite. If a short-circuit is located at a certain distance from the generator terminals, the residual voltage will be higher and as a consequence the CCT may be longer.

Exceeding the CCT will produce large currents and air gap torque fluctuations during pole slipping. If the synchronous machine is disconnected before the CCT is exceeded, these fluctuations will be smaller in amplitude and in number.

In designing the co-ordinated protection of a plant the CCT may be considered from different perspectives:

a. If the loss of a generation unit caused by a voltage dip of some duration is acceptable, the CCT will not influence the design of the protection equipment and its setting. The generator shall be tripped by an undervoltage relay to avoid pole slipping. The relay shall have preferably two voltage stages.
b. If the number of generator trips, caused by voltage dips, has to be limited, the protection equipment of the plant network has to be designed to eliminate the faults closest to the generating unit within the CCT.

Because motor loads greatly influence the CCT in plant networks, the CCT shall be calculated by a dynamic stability study taking into account the dynamic effects of motors.

The philosophy of protection settings to avoid pole slipping shall be based on two mutually exclusive main considerations:

1. The tripping of generators caused by voltage dips is acceptable because power supply is safeguarded by an external connection and island operation is not envisaged (6.4). This may be the case with PS1 and PS2 type connections in particular. Alternatively load shedding is acceptable after the tripping of generators, which may be the case with PS3 and PS4 type connections (3.6.1). In this case generators shall be tripped before the CCT is exceeded by an undervoltage relay having at least two stages.
2. The tripping of generators caused by voltage dips is not acceptable. In this case the cause of the disturbance shall be eliminated before the CCT is exceeded. Because CCTs are very short (in general 100 to 400 ms), this can only be achieved by the use of differential or distance protection relays in the plant network. An undervoltage relay as described above remains required as back-up.

6.3 OPERATIONAL CONDITIONS

Generating units shall be able to run under altered conditions. The general requirement is to keep the generating unit on line in the event of a single failure with subsequent cut-out by the protection relay to safeguard the power supply and voltage support. Under the operational conditions classified as OC1 and OC2 the performance requirements shall comply with DEP 33.65.11.31-Gen. Under these conditions they shall be able to produce rated output power at rated power factor.

For operational conditions classified as OC3 a temporary reduction in active power output to 50% is permitted. The duration may be limited on account of thermal limits but the generator connection shall be maintained for at least 1 minute (see also 6.2.1).

For operational conditions classified as OC4 no requirements in power output are given. The duration shall be limited to the shortest time dictated by the thermal limits or to 90% of the calculated CCT.

Protection settings shall be such that conditions classified as OC2, OC3 and OC4 will not lead to premature tripping.

6.4 TRANSITION TO ISLAND OPERATION

The objective of the transition to island operation is to increase the availability of the power supply to consumers. This is achieved by disconnecting one ore more generators and a relevant part of the network with its consumers from the part that is disturbed by a fault. In assessing the economic and technical benefits of a transition to island operation the following shall be considered:

1. A transition is only acceptable if the fault is located outside the electrical island.
2. The transition is always preceded by a fault that will cause large voltage deviations, fault currents and other unforeseen electrical disturbances at the generating units and the loads.
3. Because of the preceding faults, there is always a limited chance of success of the transition to island operation.
4. Because of the limited chance of success of the transition, short voltage dips have to be eliminated as far as possible to restrict the number of unnecessary transitions. The duration of the voltage dips will depend on the protection relays in use outside the island.
5. To be successful, the decision to initiate island operation has to taken quite quickly and should be co-ordinated with other protective equipment,
6. The effects of maintenance on the policy of island operation.

The success of the transition will be enhanced by:

1. A limitation of the changes before and after the transition. This can be achieved by minimising the power exchange at the disconnection point.
2. A limitation of the duration of the disturbance preceding the transition which can be achieved by a quick disconnection.

Some of the above considerations are conflicting. A balance has to be found between the reliability of the power supply from the external network, the reliability of the transition to island operation and the reliability of island operation itself.

6.4.1 Basic principles

Before implementing a facility for transition to island operation, an assessment shall be made demonstrating clearly the expected increase in availability and the economic benefits. Where statistical analysis is needed, it shall be based on sufficient local data to make such an analysis significant. The assessment shall address the following subjects as a minimum:

1. The effects and expected frequency of voltage dips and their duration caused by disturbances in the external network. The duration will be obtained from the settings of protective devices in the external network while the frequency distribution of voltage dips will be acquired from statistical analysis.
2. The effects and expected frequency distribution of outages of the power supply from the external network. The frequency distribution will be acquired from statistical analysis.
3. The technical and economic consequences of unplanned failures of the power supply caused by external faults.
4. An analysis of the expected system behaviour during and after external disturbances.
5. The expected technical and economic benefits gained by the implementation of a control and protection system for the transition to island operation.

The transition to island operation shall be based on the instantaneous voltage deviation. At the instant of voltage drop, its duration is still unknown. It may result in a short voltage dip or a temporary outage of the power supply. Basically, voltage dips of short duration do not justify transition to island operation. Beyond a certain duration (CCT), however, it is inevitable to initiate the transition to avoid pole slipping after voltage recovery. Without island operation generators may be switched off by a disturbance but generators participating in island operation shall remain connected.

A quick disconnection will shorten the preceding disturbances and gives a greater chance of success. On the other hand, the quicker the disconnection the more disconnections there will be. Availability will only be improved if the transition is sufficiently reliable. The pros and cons of shortening the disconnection delay shall be considered with respect to the number and duration of voltage dips (3.7.2) and interruptions of the power supply (3.7.1).

Considerations shall be based on the following factors liable to be improved or worsened by shortening the disconnection delay:

a. the reliability of the transition;
b. the duration of voltage dips and their effect on loads within the electrical island;
c. the frequency of transitions to island operation;
d. the need for load shedding within the island;
e. the risks of pole slipping.

The dynamic effects caused by the disturbance and the subsequent transition to island operation shall be evaluated in a dynamic analysis which shall consider the effect of voltage dips on contactors and loads and the running up of motors during and after voltage recovery.

The external network may be split, leaving part of the external network and its load connected to the plant network as an electrical island. To eliminate such an unwanted situation, an independent disconnection facility shall also be incorporated based on the frequency deviation when transition to island operation is implemented.

A special case of island operation consists of the isolation of a unit (2.2). The purpose of this mode of operation is quick recovery of the power supply. This mode of operation is defined as small island. The philosophy of small island is entirely directed towards shortening the duration of insufficient power supply or a black-out.

Within a plant network more than one electrical island may be defined.

If, during maintenance or under any other operational circumstances, island operation becomes impracticable the transition shall be inhibited within the secondary circuit.

6.4.2 Prerequisites

To implement a system for transition to island operation the following steps shall be taken:

1. Identification of the generating units able to run in island which are classified as P1. If the electrical system consists of several units, generating units classified as P2 and P3 may also form part of the electrical island providing their presence will not increase the risk of failure.
2. Distinguishing loads that shall participate in the island and those that shall not. The atter may be shedded before or at the moment of transition to island operation or be fed from outside the island.
3. Identification of the loads participating in the island and their classification as sheddable and non-sheddable during island operation. If the stand-by generation capacity allows tripping of the two largest units without shortage of power supply, a system of load shedding during island operation may be omitted. This is also the case for operation with a single generator.
4. Design of the primary circuit so that transition will be enforced by the opening of a single breaker. If an ENMC system is installed, multiple breaker action may be implemented.
5. Design of the protection system initiating the transition in such a way that co-ordination with all protective relaying is obtained.
6. Adaptation of the voltage and frequency control system of the generating units to island operation. A control signal, preferably obtained from breaker position, shall be used as input to detect island operation.
7. Ensuring that synchronisation is possible after network restoration.

Preferably the total load within the electrical island shall not exceed the generated power to avoid load shedding at the moment of disconnection. To assist the transition to island operation, a constant export of power across the coupling point should preferably be maintained. If power is imported, the power balance during or after the transition may be achieved by:

a. an increase of power generation from the spinning reserve;
b. a decrease of the load by shedding some of the non-essential services, triggered by a signal generated by the protective equipment that initiates the transition to island operation. The amount to be shed shall be sufficient to bring the load down below the running capacity under all operational conditions;
c. a combination of points a and b with the constraint that load shedding shall be based on

under-frequency.

Load shedding based on under-frequency shall be implemented within the island and used to balance the power after a generator has tripped.

The preferred configuration is given in Figures 8 and 9. The transition to island operation is achieved by opening the breaker B1. Synchronisation after voltage recovery will be achieved across the same breaker. A double busbar system (single breaker plus isolators) gives the operational flexibility of moving generators and feeders from and to the island network. This makes it easier to keep a power balance across the busbar coupler. If the transition fails, the electrical island will suffer a black out. This may last longer than voltage recovery in the external network.

Figure 8 First configuration for transition to island operation

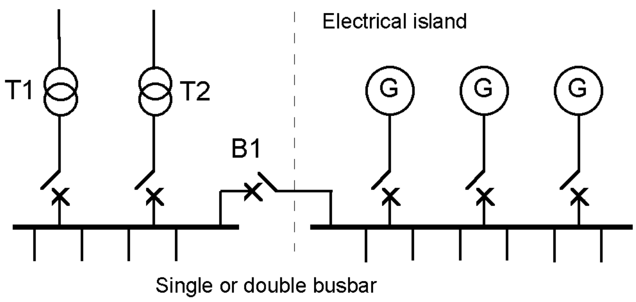
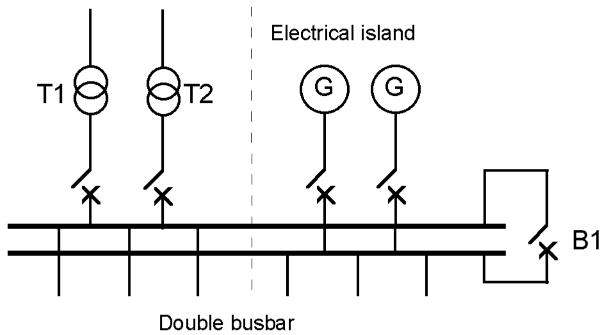


Figure 9 Second configuration for transition to island operation



6.4.3 Requirements

The detection of a substantial voltage drop and its location are the key variables for initiating island operation. It shall only be initiated if the cause of the disturbance is located outside the defined island network. This shall be detected by a directional current sensing relay at the breaker B1. The voltage signal will be taken:

1. For a PGT-type network and a small island, preferably from the primary side of the interconnecting transformer. As an internal fault will cause a smaller reduction of the voltage in the external network, it will increase the reliability of detection.
2. For a PGD-type network from the main island busbar.

The voltage relay shall have at least two under-voltage stages. The CCT shall be calculated for the residual voltage at the voltage sensor. To obtain some safety margin, the time settings, including detection and breaking time, shall be adjusted to 90% of the calculated CCT. The preferred setting for the under-voltage relay is:

- U < 40%, t = 0.90*CCT at zero residual voltage minus detection and breaker time,
- U < 60%, t = 0.90*CCT at $0.40U_n$ residual voltage minus detection and breaker time.

Additionally to and independently of the under-voltage relay, an under-frequency relay shall be used to initiate island operation in the event of splitting and loss of supply within the external network. The relay shall initiate island operation before other load shedding relays trip.

A signal shall be produced indicating whether the island network is operating in parallel or in island mode. This signal shall be taken from the breaker position.

During the transition to island operation the mode of operation of the voltage and frequency control of all generators participating in island operation shall be adjusted to operate in accordance with subsections (4.3.1) and (5.3.1). The transition from the parallel mode to the island mode of operation shall be accomplished without additional dynamic effects.

Island operation shall not be regarded as reliable without testing. By nature the testing has to be restricted to the disconnection of the island network without prior disturbance. This will be performed preferably within the secondary circuit of the protection system that initiates island operation. Before testing, the risks to operation shall be reduced to a minimum.

6.5 BLACK START FACILITIES

A black start is the condition of starting a generator unit without any electrical supply from a network. It is encountered after a black-out situation. A local power supply from batteries may be used to facilitate a black start. A generator is only able to perform a black start if it has special black start facilities. A type P4 generator unit shall have a black start facility by definition.

Each plant network shall be able to be energised after a black out. The restoration of the power supply may be done by:

1. An external feeder. For P-type networks this is the only method. Therefore, in that particular case, it is not recommended to trip the interconnection during a black out.
2. A generator unit having black start facility. For G-type networks this is the only method. Therefore, a G-type grid shall have at least two generator units with a black start facility. Maintenance will be scheduled in a way that at least one unit is permanently available.
3. An emergency generator unit which, besides supplying vital loads, is capable of supplying sufficient power to energise a part of the network and to start another generator unit without decreasing the reliability of the supply to the vital loads.

Only generator units of class P1 shall be designed with a black start facility. In a P-type network, a class P4 generator unit shall not be used to supply other loads after a black out.

An emergency generator (class P4) may only be used as black start facility for another generator provided that the power supply to vital loads is guaranteed.

If the plant network is energised with a generator unit, the effects of transformer inrush currents shall be considered to avoid the tripping of loads and generators by prolonged voltage dips. This may be overcome by slowly increasing the generator voltage with the transformer connected. In that case the generator excitation system shall provide the facility of manual control of the terminal voltage over the full range.

Emergency power generator units shall comply with DEP 33.64.10.10-Gen. and DEP 33.65.11.32-Gen.

6.6 AVAILABILITY

The availability of the power supply depends on the availability of the external grid and of the generator units.

For a given G-type network the availability of the power supply depends on the type, number and size of the installed generator units. In the economic and technical evaluation of the required number of generating units the following subjects shall be considered:

1. maintenance requirements;
2. economic size;
3. operational costs (fuel, efficiency at partial loading, maintenance);
4. availability requirements (loss of load probability);
5. unit reliability (expected number and duration of tripping events);
6. load patterns;
7. future load development;
8. start-up time of plant process after power failure;
9. dynamic effects on voltage and frequency.

In general, the traditional approach involves installing N+1 or N+2 generating units where N is the number required to supply the peak load (see DEP 33.64.10.10).

The essential purpose of the considerations, however, is to determine the number N by means of reliability calculations, economic optimisation and technical evaluations taking into account the above subjects.

7. REQUIRED TESTS

7.1 GENERAL

The tests described in this section are supplementary to DEP 63.10.08.11-Gen. They are intended to be executed as additional tests at the plant site during or after commissioning.

The tests are intended to demonstrate the capabilities of systems rather than of the single major components. During testing, the configurations of the network should be kept as similar as possible to the operational configuration.

7.2 GENERATING UNITS

Generating units shall be tested to demonstrate their capabilities of operating for a sufficient time period under deviating operational conditions. In theory, voltage and frequency deviations should be tested simultaneously but in practice this may lead to insurmountable difficulties. Therefore, tests with off-nominal voltages and frequencies may be performed separately.

The test acceptance criteria shall be:

- no tripping of the generator;
- no tripping of any protection device.

7.2.1 Frequency deviations

A network connection does not allow for any frequency deviations. These tests may be executed in island operation and shall then be limited to the generating unit and its auxiliaries. The following tests shall be executed:

1. to comply with OC2, running at 95% of the rated frequency during 10 minutes while supplying the connected auxiliaries;
2. to comply with OC3, running at 92% of the rated frequency during 5 minutes while supplying the connected auxiliaries.

7.2.2 Voltage deviations

The reference voltage will be assigned to the main busbar. The test can only be executed if this voltage can be reduced by means of a transformer with OLTC feeding the main busbar. The following tests shall be executed:

1. to comply with OC2, running at 90% of the rated voltage at the main busbar during 30 minutes while supplying rated active and reactive power;
2. to comply with OC3, running at 80% of the rated voltage at the main busbar during 5 minutes while supplying 50% of rated active power.

If the proposed voltages cannot be achieved the lowest accessible voltage will be applied.

During the test the supply to the auxiliary consumers shall correspond with the normal operational configuration.

7.3 PRIME MOVERS

To evaluate their dynamic performance, the primary governor control systems of generating units classified as P1, P2 and P4 shall be tested for their response to small signals. The test shall be executed at rated speed and rated voltage and at 20% and 80% initial loading by a stepwise increase of the reference value of the frequency or power control leading to an increase of output power of approximately 20%. The results of the test shall be given as time responses to step changes, indicating the following performance values of the active power output:

1. rise time (t_r);
2. overshoot (d);
3. time to reach peak value (t_p);
4. settling time (t_s).

The following parameters shall be plotted against time on a suitable recorder:

a. the generator output active and reactive power;
b. the generator terminal voltage;
c. the changed reference value.

The Manufacturer/Supplier shall provide the Principal with a diagram in the time domain showing the complete model of the primary frequency and power control system including the prime mover and all parameters necessary to perform dynamic simulations. It shall also include all applicable ceiling values.

To evaluate the maximum rate of change of the electrical power output a test shall be carried out by increasing the output power from the minimum to the maximum value. As a minimum the quantities given under points a and b shall be recorded relative to time.

7.4 EXCITATION SYSTEMS

To evaluate its dynamic performance, the primary excitation control system of each synchronous generator shall be tested for its response to small signals in accordance with IEC 60034-16-3. The test shall be executed at rated speed and rated voltage. The results of the test shall be given as time responses to step changes indicating the following performance values of the terminal voltage:

1. rise time (t_r);
2. overshoot (d);
3. time to reach peak value (t_p);
4. settling time (t_s).

The impressed step change of the reference voltage shall amount to +10%. Because the responses may be asymmetric, compound excitation systems shall also be tested for a step change of -10%. The following time responses shall be measured on a suitable recorder:

- the exciter or generator field voltage;
- the generator terminal voltage;
- the changed reference voltage.

The Manufacturer/Supplier shall provide the Principal with a diagram in the time domain showing the complete model of the excitation system and its parameters necessary to perform dynamic simulations. It shall also include all applicable ceiling voltages.

7.5 AUXILIARIES

Auxiliaries shall be tested for their ability to withstand short voltage interruptions. Prior to the test the generating unit shall be loaded to rated active and reactive power.

The test consists of a forced voltage interruption for one second of the supply to the main auxiliary switchboard. The interruption shall be obtained by opening and reclosing-the appropriate breaker.

If the supply to the auxiliaries is safeguarded by an ACO, it shall only be kept in operation during the test provided that the stand-by power supply is fully independent of the main supply.

The test is successful if the generator is not tripped and regains its initial power output.

7.6 CONTROL SYSTEMS

This test covers the primary, secondary and tertiary voltage and reactive power control and the primary, secondary and tertiary frequency and power control. It shall demonstrate the capabilities of the whole control system for meeting the required performance levels.

The test shall be executed under normal plant operating conditions.

The Manufacturer shall indicate which test has to be performed on the control system to evaluate the appropriate performance of the system covering all controlled equipment within the entire plant network. The testing method shall be subject to agreement between the Principal and the Manufacturer.

The Manufacturer shall submit a proposal for tests for review by the Contractor/Principal which shall be representative for operation of the control system. Items to be specified are:

- the normal operational conditions to be tested;
- the sudden changes in voltages and power output;
- all modes of operation specified for the control system;
- the kind of tests to be carried out;
- the conditions under which the test shall be performed;
- the procedures to be followed;
- the evaluation criteria of the test results.

All functions implemented in the control system shall be tested. Test protocols and criteria shall be agreed upon between the Manufacturer and the Principal.

Test results shall be measurable. The performance of the test object shall be clearly specified in terms of conditions, inputs and outputs. The specification of the whole system or relevant part shall form the basis in all cases.

7.7 TRANSITION TO ISLAND OPERATION

The test of the transition to island operation shall demonstrate the capability of the island network to operate in that condition for at least one hour.

Prior to the test, normal plant operating conditions will be maintained with the appropriate generating unit and consumers in operation giving the highest power exchange. If during normal plant operation import to and export from the island are to be expected, the test shall be performed for the highest levels of both conditions.

The test shall be executed by impressing a signal into the secondary circuit of the protective device that initiates island operation. If automatic synchronisation is installed, it shall be blocked to avoid immediate reconnection.

Restoration of the connection to the public network shall be accomplished by releasing the automatic synchronisation manually.

8. TECHNICAL AGREEMENTS WITH PUBLIC ELECTRICITY AUTHORITIES

8.1 GENERAL

The objective of this section is to determine the major technical issues that may be subject to agreements between the plant management and the public network authorities. These agreements are not applicable by definition to G-type networks.

The agreement shall stipulate the location(s) of the point of common coupling (PCC). The PCC is preferably identical to the boundary of the rights of ownership. The PCC will be preferably chosen at the cable termination point at the side of a breaker.

The public network authority shall confirm that all temporary or permanent modes of operation within the public network that might affect the operation of the plant network shall be reported before they are implemented indicating the time and duration of the changes. This may be of utmost importance in case of changes to:

1. lines or ties in service;
2. settings of protective devices;
3. short circuit levels;
4. prevailing voltages;
5. earthing.

Within the agreements a list of signals to be exchanged between the plant and the public network authorities shall be set up. Examples of such signals are

- breaker positions;
- busbar voltages;
- frequency if island operation is possible;
- signals from protective devices.

To monitor the power quality of the electricity supply from the public grid and in the absence of other requirements, a disturbance monitor and analyser shall be installed. The signals to the monitoring system shall be taken as close as possible to the point of common coupling and shall consist of:

- voltage in three phases. If island operation is an option the voltage signals shall be taken at both sides of the PCC;
- currents in three phases;
- active power exchange,
- reactive power exchange.

8.2 FREQUENCY STABILITY

The major issue concerns the requirements imposed by the public network authority on frequency support in the event of a temporary shortage of active power and a subsequent decrease in frequency. If there are no requirements on this subject imposed by public authorities all generating units shall be excluded from frequency support of the external grid. In other cases the following units shall be excluded from frequency support:

- generators classified as P3 and P4;
- steam turbine driven generators with a rated power of 5 MW and less;
- gas turbine and gas engine driven generators with a rated power of 1 MW and less.

To satisfy the requirements of the public network authority, if all or part of the output power of a generating unit assigned to frequency support is operationally difficult to control, it may be advisable to negotiate the transfer of that power to a more convenient unit.

The following subjects shall be addressed in the agreements with the public network authority:

1. If applicable, the allowable minimum and maximum frequency at which transition to island operation will take place.
2. For the generating units assigned to frequency support:
   a. the maximum power support;
   b. the amount of power support in relation to frequency;

c. the frequency threshold values to start and stop support;
d. the maximum duration of the support.

8.3 VOLTAGE STABILITY

On the subject of voltage stability the following subjects shall be addressed in the agreements with the public network authority:

1. The continuous minimum and maximum voltage at the PCC as well as the expected average operational voltage.
2. The allowable voltage deviations at the PCC caused by operational activities within the plant grid such as the starting of motors and the tripping of generators.
3. A guarantee of the minimum and maximum prevailing short circuit levels with and without the contribution of the plant network.
4. For transformer interconnections with OLTC under control of the public network authority, the settings of the OLTC control.
5. If applicable, the acceptance of a temporary island mode of operation and the minimum required time delay before initiating island operation in relation to voltage and frequency conditions.

8.4 ACTIVE POWER EXCHANGE

Technical agreements on active power exchange are closely connected to financial agreements. Active power exchange may be subject to constraints and penalties if in excess of the agreed level.

The following subjects will be addressed in the agreements with the public network authority:

1. The location and the accuracy of the accountable metering. The location of this should be at the PCC.
2. The voltage and frequency boundary ranges applicable to the agreements on active power exchange.
3. Guarantees not to exceed certain fixed maximum allowable power levels under import and export conditions.
4. The time average of the measured active power.
5. The allowable bandwidth within which no control action will be undertaken.

Items 2 and 3 shall only be part of an agreement at the insistence of the public network authority.

8.5 REACTIVE POWER EXCHANGE

Limitations to the reactive power exchange are in most cases only favourable to the public network authority. They shall only form a part of agreements at the insistence of the public network authority or if they are beneficial.

The following subjects will be addressed in the agreements with the public network authority:

1. The location and the accuracy of the reactive power metering. The location shall be identical to that of the active power metering.
2. The voltage boundary ranges applicable to the agreements on reactive power exchange.
3. Guarantees not to exceed a maximum allowable power factor in import and export conditions. The power factor at import may be different from export.
4. The time average of the measured reactive power.
5. The allowable bandwidth within which no control action will be undertaken.

8.6 EARTHING

The agreement shall state the method of earthing the neutral points within the plant network in relation to the external grid.

8.7 SYNCHRONISATION

Synchronisation between the public and the plant network is only relevant to PG-type networks. The main purpose of agreements on this subject is to avoid faulty synchronisation by either party.

The agreement shall address the following subjects:

1. The criteria concerning voltages, frequency and other operational conditions that make synchronisation permissible.
2. The information signals from both parties describing the condition of both networks.
3. The procedures to be followed before, during and after synchronisation.

8.8 PROTECTION

The settings of the protection devices of the interconnections and the disconnection criteria for island operation shall be included in the agreements with the public network authority. This is also applicable to other protective devices that may influence the protection co-ordination of the network.

Furthermore the following items shall be included in the agreements:

1. Arrangement on interlocks.
2. Accessibility to substations and switching rooms.
3. Provisions to make the recorded data obtained after faults available to the other party.
4. Specification of physical telecom connections.
5. Communication procedures based on appropriate standards from DEP 33.64.10.32-Gen.

8.9 HARMONICS

Harmonic currents are the cause of harmonic voltage distortions which may cause the malfunction of equipment. Harmonic currents may be injected within the plant grid as well as in the public grid.

Agreements on the subject of harmonics shall be based on IEC 61000-3-6. It shall be made clear which part of the harmonic distortion comes from the public grid and which part originates from the plant grid.

With respect to power quality, the performance of the public utility will be assessed according to EN 50160.

8.10 MAINTENANCE

The times to be scheduled for maintenance of the major network components that will influence the power exchange or reduce the capabilities of the network shall be subject to consultations and agreements between the plant management and the public network authority.

As an example the following components may be included:

- interconnecting transformers, cables and overhead lines;
- generating units within the plant grid;
- busbar systems and breakers;
- other connections within the public network that may reduce transmission capabilities to the plant network.

If maintenance leads to a reduced availability or capacity of the power supply from the public network an increase of spinning reserve may be considered.

9. REFERENCES

In this DEP reference is made to the following publications:

Note: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments, supplements or revisions thereto.

SHELL STANDARDS

Index to DEP publications and specifications	DEP 00.00.05.05-Gen
Electrical engineering guidelines	DEP 33.64.10.10-Gen.
Electrical network monitoring and control system	DEP 33.64.10.32-Gen.
Synchronous AC generators (amendments/supplements to IEC 34-1)	DEP 33.65.11.31-Gen.
Packaged unit AC generator sets	DEP 33.65.11.32-Gen.
Power transformers (amendments/supplements to IEC 76 and IEC 726)	DEP 33.65.40.31-Gen.
Field commissioning and maintenance of electrical installations and equipment	DEP 63.10.08.11-Gen.

EUROPEAN STANDARDS

Voltage characteristics of electricity supplied by public distribution systems.	EN 50160

Issued by:
CEN Secrétariat Central
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INTERNATIONAL STANDARDS

Rotating Electrical Machines:

- Part 1:	Rating and performance		IEC 60034-1
- Part 4:	Methods for determining synchronous machine quantities from tests		IEC 60034-4
- Part 16:	Excitation systems for synchronous machines		
	Section 1:	Definitions	IEC 60034-16-1
	Section 2:	Models for power system studies	IEC 60034-16-2
	Section 3:	Dynamic performance	IEC 60034-16-3

International electrotechnical vocabulary	IEC 60050

Electromagnetic compatibility:

- Part 3:	Limits		
	Section 6:	Assessment of emission limits for distorting loads in MV and HV power systems	IEC 61000-3-6
- Part 4:	Testing and measuring techniques		
	Section 11:	Voltage dips, short interruptions and voltage variations immunity tests	IEC 6100-4-11

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APPENDIX 1 EXAMPLES OF CLASSIFICATIONS

In this appendix some examples are given to clarify the use of classifications as given in (3). Classification itself is not a reason for the choice of equipment or system lay-out; such choices are dictated by process constraints and technical and economic evaluations. Afterwards, a classification is performed to make choices on control and operations.

First example:

Supplementary information on the generator units and the network shown in Figure A.1 is given in Table A.1. With this information a classification can be made as shown in Table A.2.

Figure A.1: First network example

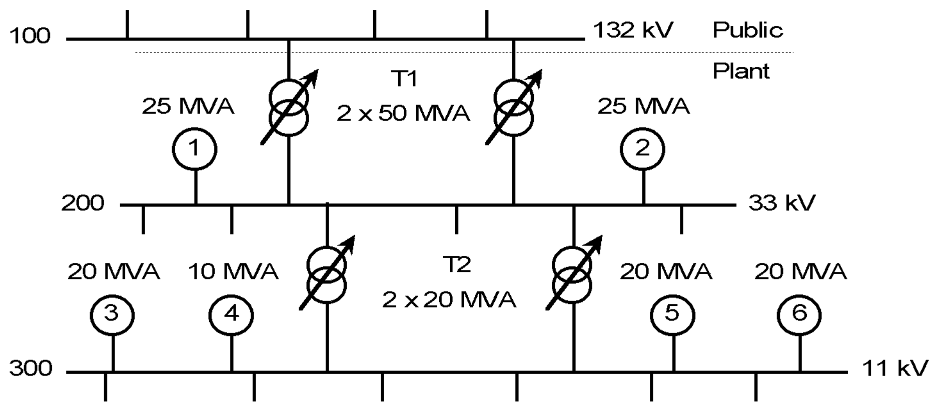

Table A.1: Typical data of the network in Figure A.1 for classification purposes

Equipment	ID	Description
Type of prime mover	1, 2 and 5	Gas turbine with dual fuel supply from proces or natural gas. Exhaust gas from GT conducted to boiler may be bypassed if necessary.
	4	Back pressure steam turbine
	3 and 6	Gas turbine on proces fuel with some buffering
Excitation system	1, 2, 4, 5 and 6	Compound source excitation system with brushless exciter
	3	Static excitation system fed from terminal voltage
Loads	Bus 200	15 MVA
	Bus 300	70 MVA
AC component	1, 2	2 kA each
of the initial	3, 5, 6	5 kA each
three phase	4	2.5 kA each
short circuit	T1	7 kA each
current (I_k")	T2	4 kA to bus 300 and 1 kA to bus 200 each

Table A.2: Classification derived from Figure A.1 and Table A.1

Subject	Unit	Class	Remarks
Generating units	1,2 and 5	P1	Fully independent because of dual fuel capabilities and exhaust gas bypass
	4	P3	Output power depends on heat generation process
	3 and 6	P2	Restricted control of output power because of fuel buffer
Generators	1, 2, 4, 5 and 6	G1	Excitation power independent of busbar or auxiliary voltage
	3	G2	Excitation power depends on busbar voltage
Type of net-work	PGT-type	Q2	derived from lay-out
Power supply capability by ties	Plant	PS4	With redundancy N+1, the ties are not able to supply the total load or to export the total generated power.
	Bus 300	PS4	Classification of an internal tie, ditto
Short circuit contribution from ties	Plant	SC1	From transformers T1, I_k" = 14 kA and from generators and T2 I_k" = 6 kA. From transformers T1 controlling the voltage of bus 200 S_k" = 70%
	Bus 300	SC3	From transformers T2, I_k" = 8 kA and from generators I_k" = 17.5 kA. From transformers T2 controlling the voltage of bus 300 S_k" = 31.4%

Second example:

Supplementary information on the generator units and the network shown in Figure A.2 is given in Table A.3. With this information a classification can be made as shown in Table A.4.

Figure A.2: Second example of network

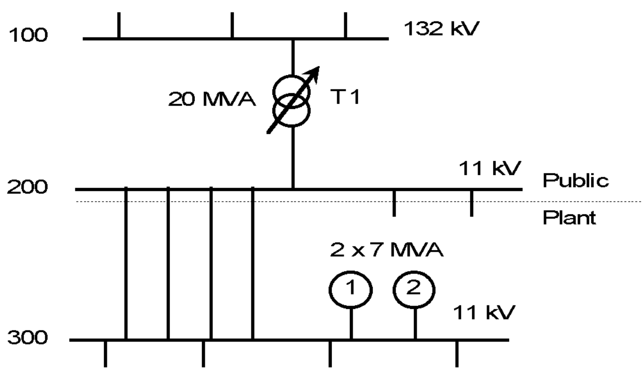

Table A.3: Typical data of the network in Figure A.2 for classification purposes

Subject	Object	Description
Type of prime mover	1, 2	Gas turbine supplied with natural gas. Exhaust gas from GT conducted to boiler may be bypassed if necessary.
Excitation system	1, 2	Compound source excitation system with brushless exciter
Loads	Bus 300	17 MVA
Capacity	Ties	20 MVA, 5 MVA for each tie
Short circuit currents	1, 2	2.5 kA each
	T1	9 kA
	Ties	9 kA, for each connection 2.25 kA

Table A.4: Classification derived from Figure A.2 and Table A.3

Subject	Unit	Class	Remarks
Generating units	1,2	P1	Fully independent of process
Generators	1, 2	G1	Excitation power independent of busbar or auxiliary voltage
Type of net-work	GPT-type	Q1	
Power supply capability by ties	Plant	PS3	With redundancy N+1, the ties are not able to supply the total load but are able to export the total generated power.
Short circuit contribution from ties	Plant	SC1	From ties T1, I_k" = 9 kA and from generators I_k" = 5 kA. From transformers T1 controlling the voltage of bus 200 S_k" = 64%