

PETRONAS TECHNICAL STANDARDS

MANUAL

Electrical Supply And Generation – Design And Operation

PTS 33.64.10.12

FEBRUARY 2011



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This revision of PTS **33.64.10.12 – Electrical Supply And Generation - Design And Operation (February 2011)** has been reviewed and updated to incorporate PETRONAS Lessons Learnt, Best Practice and new information issued by relevant industry code and standards. All updates in the document are highlighted in *italic* font (if any).

The previous version of this PTS **33.64.10.11 – 33.64.10.12 – Electrical Supply And Generation - Design And Operation (February 2010)** will be removed from PTS binder / e-repository from herein onwards.

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PREFACE

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1. INTRODUCTION

1.1 SCOPE

This new PTS 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 PTS 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 PTS shall be used in conjunction with related PTSs:

- 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.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

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This PTS is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and supply/marketing installations.

If national and/or legal regulations exist in which some of the requirements may be more stringent than in this PTS, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this document which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the objective of obtaining agreement to follow this document as closely as possible.

1.3 CROSS-REFERENCES

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

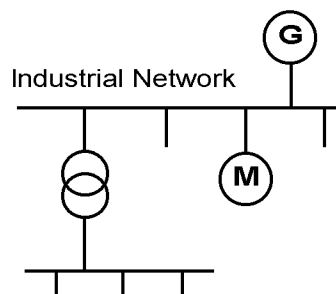
the ability of a maintenance organization, under given conditions, to provide upon demand the resources required to maintain an item, under a given *maintenance policy*.

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 <i>electrical power network</i> which represent(s) the boundaries of administration and/or ownership between the different parts of that <i>electrical power network</i> .
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 <i>isolation of the unit</i> .
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

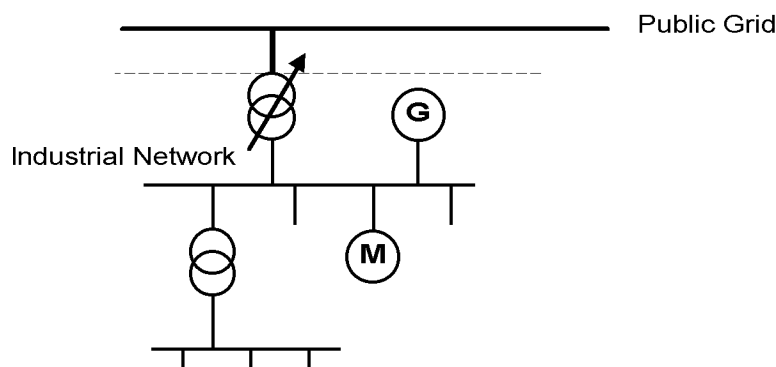
G(Generation)-Type Network: electrical network, self supporting, no coupling to the public network possible.

Figure 1 G-type network



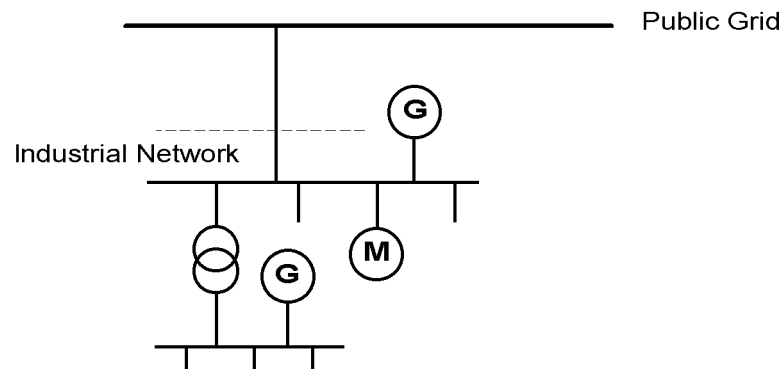
PGT(Public/Generation, Transformer connected)-Type Network: electrical network coupled to the local public network through transformer with on load tap changer, own generation in parallel.

Figure 2 PGT-type network



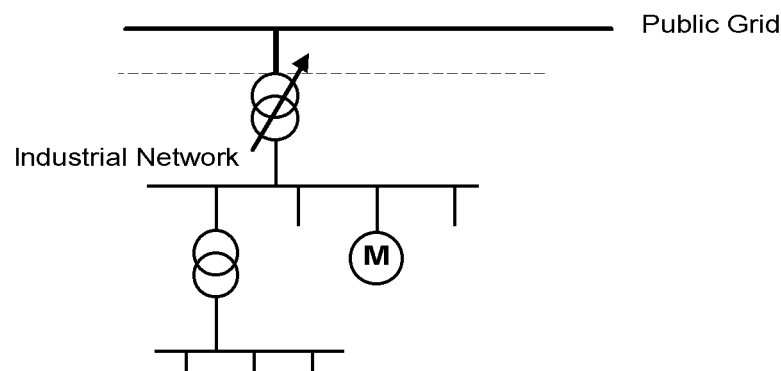
PGD(Public/Generation, Directly connected)-Type Network: electrical network coupled directly to the local public network, own generation in parallel.

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 PTS and is not related to other standards or PTS 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 PTS 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	$0.95 \leq U \leq 1.05$	$0.98 \leq f \leq 1.02$	Normal operational conditions, equipment is able to perform all primary functions continuously
OC2	Sustained	$0.90 \leq U < 0.95$ $1.05 < U \leq 1.10$	$0.95 \leq f < 0.98$ $1.02 < f \leq 1.03$	Abnormal operational conditions without loss of generation or load
OC3	Deviated	$0.70 \leq U < 0.90$	$0.92 \leq f < 0.95$ $1.03 < f \leq 1.10$	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 PTS 33.64.10.10. 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 PTS 33.65.11.31.

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 distinction 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	[%]	$U \leq 1$	$1 < U \leq 40$	$40 < U \leq 70$	$70 < U \leq 90$
Duration	[ms]	$10 < t \leq 100$	$100 < t \leq 500$	$100 < t \leq 500$	$500 < t \leq 1000$

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 PTS 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.