GENERATING SYSTEM MODEL GUIDELINES

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0.2	13 December 2007	Paul Ravalli	Changes in accordance with the Draft Determination and Report
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Please Note

From 1 July 2009, obligations relating to the Generating System Design Data Sheets and Generating System Setting Data Sheets that were NEMMCO's were transferred to AEMO.
In this document:

- quoted Rules are those that applied at the time of the consultation and have not been changed to reflect the current Rules. It is recommended that the latest version of the Rules be consulted in determining appropriate obligations; and
- in the general text, where appropiate, references to NEMMCO have been changed to AEMO.

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Table of Contents

1. Introduction

These *Generating System Model Guidelines* **(Model Guidelines)** set out *AEMO's* requirements for the development of generating *plant* models, as required by *Rule* S5.5.7 of the National Electricity Rules (*Rules*), which states:

"S5.5.7:

a) *NEMMCO* must, subject to paragraph (b), develop and *publish* by 1 March 2008, in accordance with the *Rules consultation procedures:*

   1) a *Generating System Design Data Sheet* describing, for relevant technologies, the *generating system* design parameters of *generating units* and *generating systems* including *plant* configurations, impedances, time constants, non-linearities, ratings and capabilities, to be provided under clauses S5.2.4 and this schedule 5.5;

   2) a *Generating System Setting Data Sheet* describing, for relevant *generation* and *control system* technologies, the *protection system* and *control system* settings of *generating units* and *generating systems* including configurations, gains, time constants, delays, deadbands, non-linearities and limits, to be provided under clauses S5.2.4 and this schedule 5.5; and

   3) *Generating System Model Guidelines* describing, for relevant *generation* and *control system* technologies, *NEMMCO's* requirements when developing mathematical models for *generating units* and *generating systems*, including the impact of their *control systems* and *protection systems* on *power system security*,

   and there must be a *Generating System Design Data Sheet*, *Generating System Setting Data Sheet* and *Generating System Model Guidelines* in place at all times after that date.

b) When developing and *publishing* the *Generating System Design Data Sheet*, *Generating System Setting Data Sheet* and *Generating System Model Guidelines* under paragraph (a), *NEMMCO* must have regard to the purpose of developing and *publishing* the sheets and guidelines which is to:

   1) allow *generating units* and *generating systems* to be mathematically modelled by *NEMMCO* in load flow and dynamic stability assessments with sufficient accuracy to permit:

      (i) the *power system* operating limits for ensuring *power system security* to be quantified with the lowest practical safety margins;

      (ii) proposed *access standards* and *performance standards* of *generating units* and *generating systems* to be assessed; and

      (iii) settings of *control systems* and *protection systems* of *generating units*, *generating systems* and *networks* to be assessed and quantified for maximum practical performance of the *power system;* and

2) identify for each type of data its category in terms of clause S5.5.2."

This document describes:

- the functional requirements for static and dynamic models;
- the requirements for accuracy of such models;
- the documentation that must accompany a suitable model; and
- the requirements for validating the model.

It covers the requirements for:

- steady state analysis (load flow);
- fault calculations;
- transient stability analysis (10 ms to 30 s timeframe);
- oscillatory stability (eigenvalue) analysis;
- medium and long term dynamic studies (30 s to 10 min);
- sub-synchronous resonance studies; and
- harmonics analysis.

a) These **Model Guidelines** commences on 29 February 2008.

b) These **Model Guidelines** may only be amended in accordance with *Rule* S5.5.7(c).

c) If there is any inconsistency between these **Model Guidelines** and the *Rules*, the *Rules* will prevail to the extent of that inconsistency.

2. Enforceability of the Model Guidelines

These **Model Guidelines** are enforceable in accordance with *Rules* 5.3.9, 5.7.6 and S5.2.4.

3. Definitions and interpretation

a) In these **Model Guidelines**, a word or phrase **in this style** (bold text), has the meaning set out opposite that word or phrase in the Glossary (Schedule 1) of this document.

b) If a word or phrase *in this style* (italicised text) s not defined in the Glossary, the term has the same meaning as given to that term in the *Rules*.

c) Unless the context otherwise requires, these **Model Guidelines** shall be interpreted in accordance with Schedule 2 of the *National Electricity Law*.

4. Application of the Model Guidelines

Persons required under the *Rules* to provide *generating system* models to a *Network Service Provider* and *AEMO*, i.e.:

- *Generators* and
- persons intending to connect a *generating system* to the *national grid*.

must develop the *generating system* models in accordance with these **Model Guidelines**.

5. Model Requirements

Information required for the modelling of *power system plant* for load flow and dynamic stability assessments of the *power system* is required in a number of forms. For example:

- the *Generating System Design Data Sheets* and *Generating System Setting Data Sheets* (collectively referred to as the **Data Sheets**), required to be provided under *Rule* S5.2.4(a);
- functional block diagram information, required to be provided under *Rule* S5.2.4(b)(5); and
- model source code information, required to be provided under *Rule* S5.2.4(b)(6).

This model information must be consistent. For example:

- the specific parameters relevant to a dynamic model, required in tabular form by **Data Sheets**, are expected to be found in the functional block diagrams, also required by the **Data Sheet** tables[1];
- the functional block diagrams, required by the **Data Sheet** tables, are required to match the functional block diagram required to be provided under *Rule* S5.2.4(b)(5); and
- the functional block diagram, required to be provided under *Rule* S5.2.4(b)(5), are required to match model source code information required to be provided under *Rule* S5.2.4(b)(6).

5.1 Variation Request

Unless the affected *Network Service Provider* and *AEMO* agree otherwise in writing, a *Generator* or *Connection Applicant* must provide all of the information required by these Guidelines. A request for a variation to the requirement to provide all of the information required by these Guidelines from a *Generator* or Connection *Applicant* **(Variation Request)** must detail:

- the specific requirement(s) that cannot be met;
- a description of the reasons why each of the requirements cannot be met;

[1] the identical numerical value may not match between the parameter requested in the table and the functional block diagram due to differences in units, or a requirement to provide parameter information in a functional block diagram in 'per unit' form, however, it is expected that the parameter is recognisable in the functional block diagram.

- if there is a discrepancy between a requirement and what can be provided, a description and extent of the discrepancy;
- if a requirement can be met at a later date, an undertaking as to when and how it would be met;
- if the discrepancy between a requirement and what can be achieved could be reduced at a later date, an undertaking as to when and how this would be provided;
- documentary evidence (including options considered) of the reasons for being unable to meet a requirement, sufficient to satisfy the *Network Service Provider* and *AEMO* that meeting the requirement is technically unachievable; and
- the extent to which that requirement might affect the ability of the *Network Service Provider* or *AEMO* to assess *performance standards* for the relevant *generating unit* or *generating system*.

The *Network Service Provider* and *AEMO* must consider a **Variation Request** in terms of its impact on:

- the model (to which the **Variation Request** is related), and how it should be used;
- quality or security of *supply* to *Network Users*;
- the calculation of *network* limits;
- the ability for the *Network Service Provider*, *AEMO*, the *Connection Applicant* or any other party allowed under the *Rules* to conduct studies for *connection* applications and access negotiations;
- the extent of changes to the operation of the *generating system* under *Rule* 5.7.3(f).

Following consideration of the **Variation Request**, the *Network Service Provider* and *AEMO* must:

- accept or reject it;
- propose alternatives or options for the *Generator* or *Connection Applicant* to consider; or
- request further information.

AEMO declares the **Variation Request** and any accompanying information or documentation to be *confidential information* under *Rule* 8.6.

5.2 Document requirements

5.2.1 General documentation requirements

Information to be provided with any model, or data used for modelling purposes required by the **Data Sheets**[2], must include:

- how the model is to be set up for *power system* analysis (including expected operational practice); and
- any other information the *Generator* or *Connection Applicant* considers relevant to the performance of the *generating plant* for the model's intended use or to achieve the relevant accuracy requirements.

5.3 Validation requirements

Each model must be developed and tested to the extent reasonably necessary to establish that it will meet the accuracy requirements described for the relevant model type. In order to achieve this:

- during the *generating system* design and development stages, it is expected that the model will be rigorously derived from design information; and
- parameters and models that are designated as 'R2' in the **Data Sheets** must be derived from on-site tests.

Parameters, other than those designated as 'R2' in the **Data Sheets***,* that contribute most significantly to the accuracy of the model for fault, *voltage* and *frequency* disturbances in the *power system*, must be derived from on-site tests, where possible.

Where parameters are not designated as 'R2' in the **Data Sheets** there remains the requirement to validate the value of these parameters (in aggregate) through the validation of the overall performance of the system, device, unit or controller to which they pertain.

6. Load Flow and Short Circuit Model Requirements

6.1 Functional Requirements

The load flow and short circuit model must define the steady state and quasi-steady state behaviour of the *generating system* over its operating range. It is provided as per the requirements of *Rule* s5.2.4(b).

[2] for example, an explicit model is not required for medium and long term studies, and information in the **Data Sheets** is expected to be sufficient for modelling purposes. Where such information is provided, additional information, requested by the *Network Service Provider* or NEMMCO on the modelling requirements for this data, must be provided.

6.1.1 Steady State Behaviour

'Steady state' behaviour refers to the electrical conditions prevailing in any 50Hz steady state of the *power system* after decay of transients, under either normal or contingency operating conditions for the *power system* and in the absence of short circuits.

The model must be capable of representing the entire range of steady-state operating conditions for each *generating unit* and the *generating system* under the full range of feasible steady-state *network* conditions. In this case, a feasible steady-state *network* condition is any condition that can exist for 10 seconds or more under the *system standards* and the *network* performance requirements, if any, that the *Network Service Provider* is required to meet under any *jurisdictional electricity legislation*.

6.1.2 Quasi-Steady State Behaviour

'Quasi-steady state' behaviour refers to the electrical conditions prevailing in the *power system* during the occurrence of a short circuit fault (which may be single phase to ground, phase to phase, two phase to ground, or three phase, and may involve a non-zero fault impedance). The *network* might be in either normal or contingency operating conditions prior to application of the fault, and the fault might occur at any point in the *network,* including a *generating unit's connection point*.

For most design purposes, the data provision requirements in the **Data Sheets** will be sufficient.

Where requested by a *Network Service Provider* or *AEMO*, some additional information may be required, such as:

- for *plant* incorporating any power electronic devices, a description of how that device should be included in a load flow fault calculation; or
- where required by a *Network Service Provider* or *AEMO*, sufficient data to calculate the AC and DC components of the fault current using an electro-magnetic transient (EMT) calculation program.

6.2 General Requirements for Load Flow and Short Circuit Model

The load flow and short circuit model and the associated model parameter values must:

- represent each *generating unit* and other *plant* at their respective terminals to the accuracy levels described in Section 6.3;
- be capable of representing the *generating system* for all feasible steady state output levels and, where the fuel source is not controllable (e.g. wind), for all possible values of source strength where the *generating system* would be in operation;
- include an explicit representation of all relevant *generating unit plant*, all *transformers* (including tap-changer information) and any other relevant primary *plant* within the *generating system*; and

- include descriptions and setting values for control schemes (e.g. *reactive power*, *power factor* and *voltage* controls, and any control schemes that may limit the capability of any *generating system* primary *plant* or affect how that *plant* responds) that are relevant to the intended use of the model.

6.3 Accuracy Requirements

The model must accurately represent the performance of the *generating system* at its terminals. That is, the model must respond accurately when compared to the actual *generating system* response for the same disturbance.

In order to achieve this, the following performance measures must be used to determine the model requirements. It should be noted that all of the following criteria apply in conjunction, and no criterion should override another, except where specifically noted:

1. Taking into account the *voltage* at the *connection point*, the deviation of the *plant* model from the actual *plant* response for *active power* and *reactive power* must not exceed 10% of the total change in that quantity.
2. The model must not show characteristics that are not present in the actual *plant* response.

7. Transient Stability Model Requirements and Oscillatory Stability Model Requirements

7.1 Functional Requirements

The transient stability model must define the electromechanical and *control system* performance of the *plant* within a *generating system* under steady state and disturbance conditions. It is provided as per the requirements of *Rule* s5.2.4 (b).

That *plant* includes the *generating unit* or any other primary *plant* within the *generating system* that may affect the overall interaction (*active power*, *reactive power* or *voltage*) of the *generating system* with the *power system* (e.g. *reactive power* compensating *plant*). Disturbances include any, or a combination, of:

- a fault remote from the *generating unit*;
- a fault at, or close to, the *connection point*;
- a line or other *plant* switching or tripping;
- a trip, with or without a fault, of one or more *generating units* (from that or another *generating system*) or customer *load*;
- a *voltage* disturbance that could be of short or long duration (e.g. as could occur when a part of the *network* is close to *voltage* collapse); or
- a *frequency* disturbance (e.g. as could occur when a part of the *network* is islanded).

The transient stability model and the associated parameter values must:

- be capable of being implemented in one of the power system software simulation products described in section 7.2;
- be capable of representing each *generating unit* at its terminals to the accuracy levels described in Section 7.3;
- be capable of representing the *generating system* for all possible steady state output levels, and for all possible values of source strength where the *generating unit* or *generating system* would be in operation. In the case of *generating units* with an inherently variable power source, where the variability of the source is not specifically the subject of the study, the model may assume the source strength remains constant throughout the simulation study.
- provide for an explicit representation of all generating *plant* within the *generating system*, including *generating units*, *tap-changing transformers*, and *reactive power* compensating *plant*.
- be in functional block diagram format. In showing 'functionality', the model is expected to bear some resemblance to the physical design of the *plant* and controllers. The dynamic characteristics described within the functional block diagram must:
  - be described by Laplace (preferred) or Z-domain transfer functions wherever possible. The transfer function blocks and model parameters must be recognisable in terms of the physical design of the *plant* and actual *control system* settings, to allow the *Network Service Provider* or AEMO to assess *control system* settings proposed by the *Generator* or *Connection Applicant*, or design new settings;
  - include any relevant non-linearities, such as limits, arithmetic or mathematical functions, deadbands or saturation, etc. Any limits must be shown as windup or non-windup limits. Non-windup limits must show how the non-windup nature of the limit is achieved (e.g. which model state variable is being limited and the relationship between the limit value and the state variable that is being affected by that limit);
- include descriptions and setting values for control sequences (e.g. fault ride-through control schemes and any other relevant *control systems*) that are relevant to the intended use of the model described above;
- include any other controllers that can adjust the *generating system* output or affect its performance in the time domain simulation timeframe (e.g. governor action);
- have a bandwidth of at least 0.05Hz to 10Hz (for that part of the response that is linear) and settle to the correct final value for the applicable *power system c*onditions and applied disturbance(s); and
- allow numerically stable and accurate performance for time step sizes down to 1 millisecond and in any event must be able to operate stably and accurately for a time step size of 1 millisecond. Time constants less than 5ms should only be included if their inclusion is critical to the performance of the dynamic model for the purposes described above and the accuracy requirements.

The requirements for an oscillatory stability model are very similar, except that:

- they account for non-linear elements through an appropriate mathematical linearisation method (which takes into account the operating point); and
- since oscillatory stability is calculated in the frequency domain, there is no integration time-step requirement.

A fully validated transient stability model is a sufficient model also for linear systems analysis (oscillatory stability), provided that the oscillatory stability model can be derived from the transient stability model using standard mathematical linearisation techniques (this is normally the case). If this is not the case, a separate model must be provided, with any relevant information concerning the parameter values at different *generating unit* operating points.

7.2 Documentation for transient stability models

Information to be provided with the transient stability models must include:

- model source code. The source code must be unencrypted for at least one of the software simulation products nominated by *AEMO*, to allow *AEMO* to convert the model for use with other software packages. Suitable software packages are listed on the *AEMO* website at:

  http://www.aemo.com.au/registration/118-0001.html

- a manual for the model that describes:
  - the components of the model;
  - the model parameters;
  - any specific requirements of the *power system* model that must be applied (e.g. *network frequency* dependence); and
- how the model is to be set up for *power system* analysis, including:
  - initial conditions setup if this is different from the load flow information provided under Section 6 and Section 5.2.1, and
  - where a *generating unit* model will be 'scaled up' to represent a *generating system* model, what model parameters must be adjusted.

As explicit models are not required for medium or long term stability assessments, the transient stability model will be used for studies up to 10 minutes and is required to be numerically stable in this timeframe. Additional documentation must be provided, on request by a *Network Service Provider* or *AEMO*, in relation to how information provided by the *Generator* or *connection applicant* in the **Data Sheets** should be used in the medium to long term timeframes (i.e. up to 10 minutes). This includes *control systems*, *protection systems*, *plant* limits and limiters that are not explicitly modelled in the transient stability model, and could result in a change in output or tripping of a *generating unit* or the *generating system* due to, or as a consequence of, *voltage*, *voltage*-angle, or *frequency* at the connection point (e.g. *control system* limiters, over-*voltage* or under-*voltage protection systems*, *frequency* rate-of-change protection, etc.).

7.3 Accuracy Requirements

The model must accurately represent the performance of the *generating unit* at its terminals. That is, the model must respond accurately when compared to the actual *generating unit* response for the same disturbance.

In order to achieve this, the following performance measures must be used to determine the model requirements. It should be noted that all of the following criteria apply in conjunction, and no criterion should override another, except where specifically noted (items stuck-out do not apply):

1. For any *control system* models, the overall linear response over a frequency bandwidth of at least 0.1–5Hz must be within the following tolerances:
   - magnitude must be within 10% of the actual *control system* magnitude at any particular frequency; and
   - phase must be within 5 degrees of the actual *control system* phase at any particular frequency.
2. For time domain responses that include non-linear responses or performance, as well as responses to switching or controlled sequence events (e.g. operation of fault ride-through schemes and converter mode changes), the key features of the response are within the following tolerances:
   (a) rapid slopes in the simulated response, compared with the actual *plant* response must be within the less restrictive of:
       - 10%; and
       - from the start to the finish of the slope, 20 milliseconds.

   (b) for rapid events caused by control sequences (such as some fault ride-through control schemes) or switching events, the sizes of peaks and troughs (measured over the total change for that peak or trough) must be within 10% of the change;

   (c) oscillations in *active power*, *reactive power* and *voltage* in the frequency range 0.1 to 5Hz must have damping[3] and frequency of the oscillation within 10% of the actual response of the *plant*. The phase of the oscillations (relative to the other quantities – e.g. *active power* versus *reactive power*) must be within 5 degrees in terms of the dominant oscillatory mode. This does not apply to rapid events under item (b), but does apply to any subsequent oscillations;

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[3] Measured as a rate of decay of the oscillation – e.g. halving time.

(d) the timing of the occurrence of the rapid slopes, events or the commencement of oscillations described in paragraphs (a)-(c) must be consistent with the *plant* characteristic that initiates the response[4].

3. Taking into account the *voltage* at the *connection point*, at any point during the simulation, the deviation of the *plant* model from the actual *plant* response for *active power* and *reactive power* must not exceed 10% of the total change in that quantity. During periods of oscillatory behaviour, this criterion applies to:

   (a) the first cycle of the oscillatory response after the transient period (i.e. if associated with a fault, then after clearance of the fault and the transient recovery from the fault); and

   (b) after the first cycle of the oscillatory response, to the upper and lower bounds of the envelope of the oscillatory response.

4. Taking into account the level at which *voltage* settles at the *connection point*, the final *active power* or *reactive power* value at which the model settles is within the more restrictive of:

   – the final value at which the actual *plant* response would settle ±2% of the *plant's nameplate rating*; or

   – the final value at which the actual *plant* response would settle ±10% of the total change in the quantity during the transient period during and following the disturbance.

   Where measurement results can be shown to have been affected by changes in supply source (e.g. the wind strength for a wind turbine), this shall be taken into consideration when assessing this criterion, so long as sufficient evidence can be shown to demonstrate the cause of the input power change.

5. The model must not show characteristics that are not present in the actual *plant* response.

6. The model, as implemented in the relevant software simulation product for which it was provided, must be numerically stable across a simulation time of 10 minutes.

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[4] This is a difficult criterion to specify, as it depends on what initiates the event or oscillation. Switching events or rapid control actions initiated as a result of passing a threshold level in a measured quantity and any time delays in the design of the *plant* should be straightforward to assess. It is recommended that the fallback criterion for this requirement be that:

(i) the response must be explainable; and
(ii) any inconsistency in the response should lead to an investigation to establish a plausible reason for the inconsistency. A revision to the model should be considered in the latter circumstance.

7.4 Provision of generating unit and generating system models

Sections 7.1, 7.2 and 7.3 relate to the provision of a *generating unit* model or, where agreed with *AEMO* and the *Network Service Provider* prior to these **Model Guidelines** coming into effect to a *generating system* model (i.e. in the absence of a *generating unit* model).

In terms of *generating unit* and *generating system* model provision:

- the *Generator* must provide a single *generating unit* model for each unique *generating unit* within the *generating system* and separate models for each other primary *plant* item (e.g. STATCOM, SVC or other *reactive power* compensation *plant*, transformers, etc.);
- if there is a significant computational burden by modelling each *generating unit* within a *generating system*, *AEMO* and the *Network Service Provider* may, in the first instance, scale the *generating unit* model by the number of similar *generating units*;
- a *generating unit* model must be scaleable solely by setting its MVA rating to that of the combined number of similar *generating units* in the *generating system*. That is, the parameters applicable to the model must be in per-unit on the model MVA rating;
- a *Generator* may apply to *AEMO* and the *Network Service Provider* to provide a *generating system model*. This may aggregate the *generating unit* models within a *generating system* into a single “equivalent generating unit”, however other plant (e.g. STATCOM, SVC or other *reactive power* compensation plant, transformers, etc.) must be explicitly modelled. The provision of such a *generating system* model must be in addition to the *generating unit* model;
- in making an application to *AEMO* and the *Network Service Provider* to provide a *generating system* model, the *Generator* must provide evidence of the suitability of the *generating system* model to the relevant *Network Service Provider* and *AEMO*, who must jointly assess that evidence;
- if *AEMO* and the *Network Service Provider* accept the generating system model, they may choose to use it for *power system* studies. If the aggregated *generating unit* model is found to be unsatisfactory, *AEMO* and the *Network Service Provider* may choose to revert to the “scaled-up” *generating unit* model;
- the *generating unit* model and other *plant* models in the *generating system* are the primary models for use by *AEMO* and the *Network Service Providers*, these must be validated according to the ‘R2’ specifications in the **Data Sheets**;
- provided a suitably validated *generating unit* model has been provided to *AEMO* and the *Network Service Provider*, the aggregated *generating unit* model need not be validated. This model could simply be confirmed analytically against the *generating unit* model taking, for example, appropriate levels of *generating unit* output diversity into account. The accuracy of the *generating system* model must be equivalent to the level of accuracy that would be achieved by deriving the *generating system* model from *generating unit* models that meet the accuracy requirements in this Model Guideline and, in any case, is

adequate for assessing *power system security* according to operational and planning timeframes and requirements.

8. Medium and Long Term Dynamic Model Requirements

Data provision requirements are as specified in the **Data Sheets**. Information on *control systems* requested in the **Data Sheets** must include those *control systems* that can influence *generating unit* or *generating system* performance with a 10 minute timeframe.

There is no requirement for the provision of distinct Medium Term Dynamic Models. Medium Term simulations will be based on Transient Stability Models (as described in section 7.1) and other models derived from data provided in the **Data sheets** for equipment such as on-load tap changer (OLTC) controllers, turbine governors, over-excitation or stator current limiters and any other thermal, *voltage* or *frequency* related controller with a time-delayed response.

9. Sub-Synchronous Resonance Model Requirements

Data provision requirements are as specified in the **Data Sheets**.

For any specialised analyses, such as electro-magnetic transient studies, until there is a general requirement for such models the *Generator* shall determine the degree of modelling accuracy that they believe is required to ensure that changes to the *power system* will not adversely affect the operation of their *plant*.

10. Harmonics Model Requirements

Data provision requirements are as specified in the **Data Sheets**.

For any specialised analyses, such as electro-magnetic transient studies, until there is a general requirement for such models the *Generator* shall determine the degree of modelling accuracy that they believe is required to ensure that changes to the *power system* will not adversely affect the operation of their *plant*.

SCHEDULE 1 - GLOSSARY

DEFINED TERM	***DEFINITION***
Data Sheets	collectively the *Generating System Design Data Sheets* and the *Generating System Setting Data Sheets*
Model Guidelines	the *Generating System Model Guidelines* (this document)
Variation Request	as described in Section 5.1