DEFINITION OF MODELLING STANDARDS FOR ELECTRICAL POWER SYSTEMS

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ABSTRACT

Simulation and modelling activity is becoming increasingly important to the design process for modern electrical power systems. The ability to de-risk design concepts and investigate systems integration issues, in a desktop environment, has the potential to drive down the cost of development of new systems, and encourage novel designs. Furthermore a model based design process has the potential to revolutionise the development of new systems.

At present there is no accepted definition of modelling standards. The absence of such standards is a major obstacle to the role of modelling and simulation activity within any design process. The acquisition of models that are fit for their intended purpose is not trivial. Acceptance testing is generally unstructured and subjective, rather than coherent and objective, and this can lead to protracted debate regarding the status of any modelling or simulation activity.

This article describes a framework of modelling standards to facilitate the formal specification of the requirements of a model. The framework provides a means by which the compliance of a model to its requirements may be assessed in a structured manner, resulting in an objective assessment of its fitness for purpose. The authors believe that this is the first time that all the qualities of a model have been encapsulated in a single structured framework.

Introduction

Simulation and modelling activity is becoming increasingly vital to the design process for modern marine power systems.[1] Systems such as the Electric Ship Technology Demonstrator (ESTD),[2] the WR21 Gas Turbine Alternator (GTA),[2] and the power system onboard HMS *Ocean*,[3] are all the subject of ongoing modelling and simulation programs. However there are no widely accepted standards that define the intrinsic quality of a software model.

The absence of a standard for modelling and simulation is a major issue for the Power Systems Community, and indeed for the defence community at large. Both NATO and the US DoD recognize that the formulation of a framework of modelling standards is crucial to meeting many of the stated objectives of their respective Master Plans for modelling and simulation.[4,5] It is widely recognized that the acquisition of models that are fit for their intended purpose is not trivial due to the lack of an accepted standard for modelling and simulation activity.

Attempts have been made to develop standards for modelling and simulation,[6] and these have been useful in informing the development of the proposed standard.

The only formally recognised standard for modelling and simulation is the High Level Architecture (HLA), an interface standard recognised by the IEEE.[7,8,9] However no standard has been identified, which satisfactorily describes all the intrinsic qualities of a model. The scope of HLA is limited to the communication between models, rather than the contents of those models.

Therefore a new standard is needed to frame electrical power systems modelling and simulation. The authors contend that the ESTD, WR21 GTA, and HMS *Ocean* modelling programs could have been undertaken with greater ease and efficiency had such a framework been available at the conception of those programs. Such a framework has benefit to both customer and supplier alike.

Major objectives

The widely accepted definition of the quality of a system is its fitness for purpose. Therefore the main objectives of the new modelling and simulation standard are as follows:

- To describe the requirements of a model to be developed which will enable that model to fulfil its purpose.
- To describe the capabilities of a model that has been developed, and therefore facilitate assessment as to whether that model is able to fulfil its purpose

The requirements and capabilities of a model should be described formally and unambiguously. All the qualities of a model that are pertinent to the purpose of the model should be identified. The accepted definition of quality suggests that a high quality model is fit for its intended purpose. Therefore a high quality model has capabilities that match its requirements.

Road map

MLS1, with The MathWorks Ltd assistance, have proposed a new standard for modelling and simulation of electrical power systems. It is the intention of MLS1 to formulate the standard as a Defence Standard, and interested parties are invited to contact the authors.

The anticipated steps to the creation of a new Defence Standard for Modelling and Simulation of Electrical Power Systems is as follows:

1. Announcement through Standards in Defence News.
2. Forming a Defence Standard committee, to meet during 2004.
3. Submission to the Defence Standards Agency in late 2004.
4. Addressing any issues raised by the Defence Standards Agency.

MLS1 would like to invite potential stakeholders to register an interest, with a view to sitting on the Defence Standard committee, reviewing the standard in full, or providing any other feedback.

The proposed modelling standard

The proposed standard is descriptive in nature, and is underpinned by a comprehensive glossary. The authors have identified many terms that are commonly used to describe the qualities of a model. Typical examples include fidelity, accuracy and validation. There is no consensus as to the definition of these terms. The purpose of the glossary is to remove any ambiguity from the description of the qualities of a model.

The proposed modelling standard involves the creation of a referent – a device suggested in reference 6. Clearly it is impossible to define the requirements of a model by reference to some real world object, as the real world is extremely complex, and contains many extraneous phenomena. A referent is an abstraction from the real world that contains just enough detail to support the stated purpose of the model. Once developed, the model is compared to the referent, not the real world. The purpose of a model is often well understood – the referent records the requirements of the model that must be met for the model to fulfil its intended purpose. The formal definition of a referent is twofold:

- A referent is a detailed, structured abstraction from the real world of some phenomena, system, or device. A referent describes the interesting features of the real world, but neglects the extraneous features.
- A referent is a detailed, structured, functional specification of a model or simulation.

The proposed modelling standard facilitates classification of a model using the same framework that is used to create a referent. This permits direct comparison between the requirements and capabilities of a model. Therefore the objective assessment of the quality of a model, the fitness of the model for its intended purpose, is made trivial. Furthermore the proposed standard may be used to classify any existing model, to provide a formal description of the capabilities of such models, and therefore facilitate greater model reuse.

This article will proceed to describe the proposed framework by reference to two common aspects of the quality of a model:

- Fidelity.
- Validation.

GLOSSARY

What's in a word?

Many terms are used to describe the qualities of a model. However these terms are of no use in the context of a descriptive standard, unless there is an agreed definition of each word. This is especially the case as some important terms have several equally valid, but quite different meanings. Consider the following common examples:

Fidelity

- 'The faithfulness of a model to its requirements, rather like faithfulness in marriage.'
- 'The fineness of detail present within a model.'

Accuracy

- 'The fineness of detail present within a model.'
- 'The faithfulness of a software model to its underlying mathematical model.'
- 'A measure of how closely a model predicts plant behaviour.'

The glossary within the proposed modelling standard contains approximately forty such terms. Each has been given a definition that most closely matches the combined experience of the authors. The important issue is not the precise definitions themselves, but rather that definitions are chosen and accepted. Such a pragmatic approach is essential to minimize any debate regarding the precise definition of each word.

The glossary first of all defines a number of general terms, which are used throughout the proposed modelling standard. These terms include Quality, Deficiency, Suitability, Standard, Tolerance, Error and Credibility.

The proposed modelling standard divides the qualities of a model into categories, identified by a keyword. For each keyword the glossary offers a contextual definition and a list of synonyms. The division of quality into categories, and the allocation of synonyms, greatly simplifies the process of describing quality. Table 1 lists the categories and synonyms that have been used, together with brief definitions.

TABLE 1 – *Keywords, synonyms, and brief definitions from the glossary of the proposed modelling standard*

KEYWORD(S)	SYNONYMS	BRIEF DEFINITION
Inventory Measurements		The components within a model The signals of interest within a model
Fidelity	Detail, Precision, Resolution	The granularity of detail within a model
Accuracy		A model's faithfulness to its underlying theoretical model
Efficiency Style Environment	Appropriateness Readability	How well the implementation of a model has been performed The quality of the presentation of a model The software package used to implement a model
Repeatability	Robustness, Sensitivity	The immunity of a model to external effects
Validation Accreditation	Verification	A model's ability to predict the behaviour of a real system The achievement of approval of a recognised third party
Usability	Accessibility, Clarity	The ease with which a user can operate a model or simulation.
Visibility Parameterised		The visibility of the implementation of a model The availability of model parameters
Interoperability Reusability	Compatibility Flexibility	The ability of a model to communicate with another model The ease with which a model can be recycled
Speed		How quickly a simulation runs
Volume		The volume of data produced by a simulation
Documentation		The contents of any documents that accompany a model

The widespread acceptance of a common terminology is fundamental to the success of the proposed modelling standard.

Fidelity

Fidelity is one of the most common terms used to describe a model. Therefore it seems appropriate that the definition of fidelity chosen for the proposed standard is a commonly used definition:

'The granularity of detail within a particular model, specified in terms of the components that should be included explicitly within the model, the phenomena that should be observed, or the timescales of interest.'

A high fidelity model therefore contains more detail, and permits observation of phenomena of a higher frequency, than a low fidelity model.

In the context of power systems, the fidelity of a model corresponds directly to the frequencies of phenomena observable within the model. A high fidelity model of a propulsion drive would contain explicit models of the power electronic devices, and permit observation of harmonic distortion. A low fidelity model of a propulsion drive would implement the idealized equations associated with the topology of each bridge, and permit observation of RMS values of signals.

Validation

Validation is often key to the credibility of a model. Ultimately, the validation of any model of a real system is critical to whether or not the model is of any use for predicting the behaviour of that real system. The chosen definition for validation is straightforward:

'The ability of a simulation to predict the behaviour of the system it represents.'

The scope of any validation must be defined in terms of the:

- Signals of interest.
- Frequencies of interest.
- Components that are responsible for those signals of interest.
- Operating scenario under investigation.

A fully validated model is able to predict specified measurements made within the plant that has been modelled, to within specified error bounds. A model that is not validated should nevertheless exhibit behaviour similar to the plant represented by the model.

REFERENT AND CLASSIFICATION – REQUIREMENTS AND CAPABILITIES

Fidelity

Some aspects of the quality of a model are subdivided into levels within the proposed modelling standard. Fidelity is a good example, and is divided into five levels, according to typical phenomena that might be observed within a power system:

Very high

Explicit representation of device junctions, and observation of radio frequency (RF) phenomena. Typical maximum frequency of interest – 10MHz.

High

Explicit representation of switching devices, and observation of system harmonic phenomena. Typical maximum frequency of interest – 10kHz.

Medium

Observation of phenomena of frequencies up to and including the system frequency. Typical maximum frequency of interest – 60Hz.

Low

RMS representations of all systems. Observation of phenomena of frequencies that are lower than the system frequency. Typical maximum frequency of interest – less than 60Hz.

Very Low

Steady state representation of systems. Load flow analysis, through life cost analysis. Typical maximum frequency of interest – 0Hz.

It is recognized that for a particular model, the level of fidelity appropriate for one component may be completely inappropriate for other components. A propulsion drive model is a useful example. If the purpose of a model is to investigate harmonic distortion on a distribution bus during manoeuvring of the platform, the model would include representations of the:

- Distribution network.
- Propulsion drive.
- Propulsion motor.
- Shaft line.
- Hull form.

Clearly the electrical components should be of high fidelity, to permit observation of harmonic distortion. On the other hand a high fidelity model of the hull form might include calculation of the wake angle and boundary layer thickness – clearly unnecessary in this case. A low fidelity model of the hull form would be perfectly adequate. Therefore fidelity is specified on a component by component basis.

The principle behind the description of fidelity is that if any phenomena are to be observed, the model must contain explicit models of the devices responsible for those phenomena. Hence fidelity can be specified in terms of phenomena, or devices that must be represented explicitly, or indeed frequencies of interest that correspond to the phenomena to be observed.

Table 2 presents the components needed to describe the fidelity referent and classification of a model. Note that the components of the referent and classification are directly analogous to each other, and therefore facilitate direct comparison of the requirements and capabilities of a model. For both the referent and classification, the fidelity of a model is described in terms of the levels identified above.

TABLE.2 – *Components of the fidelity referent and classification of a model*

REFERENT	CLASSIFICATION
Specify the baseline fidelity of the entire model.	Record the baseline fidelity of the entire model.
Specify the fidelity of any components and/or signals as appropriate.	Record the fidelity of each component and signal within the model.
List any phenomena to be observed.	Record any phenomena that are observable within the model output.
Five levels of fidelity are identified.	Present evidence to justify the recorded level of fidelity in each case.

The following guidelines are proposed for the description of the fidelity of a model, in the context of the referent or classification:

- The baseline fidelity applies to the whole model. Therefore all components and signals should be of at least the baseline fidelity.

- Any components or signals with a higher fidelity than the baseline should be specified separately.
- For any signal of a particular fidelity, all components that contribute to that signal must be of at least the same fidelity.
- The phenomena to be observed correspond directly to the specified fidelity of the components and signals.
- A component of a particular level of fidelity may or may not meet the requirements of any lower level of fidelity.
- The baseline level of fidelity of the model will correspond to the lowest fidelity component within the model.

Therefore the proposed modelling standard facilitates structured and unambiguous description of fidelity. The fidelity requirements and capabilities of a model may be compared directly, to facilitate assessment of fitness for purpose. Furthermore the fidelity of any existing model may be classified, to provide a comprehensive description of the capabilities of such models.

The process of formulating a referent for a model that is to be developed, and then classifying the delivered model, is intended to complement the acquisition cycle at two key stages. The formulation of a referent should be undertaken at the specification stage, and the classification of a model should be performed as part of the assessment and acceptance process.

Validation

Validation is a good example of a quality that does not divide naturally into levels. It is not obvious what factors should distinguish a high level of validation from a medium or low level of validation. Therefore the nature and scope of the validation required of a model must be specified carefully, to encapsulate any genuine requirement, while avoiding unnecessary constraints. To say 'the model performance must match the system performance' is an enormous, sweeping statement of something that is impossible either to achieve in full, or to confirm. It is tantamount to expecting a software model to behave in an identical fashion to the equivalent real world system. It may be argued philosophically that for a model to reproduce a real world system exactly, it must be the real world system. Although validation is not divided into levels there are two aspects of validation that should be considered:

Quantitative validation

Signals from the model should compare favourably to signals measured on the represented system, and should agree to within specified error bounds.

Qualitative validation

The model should exhibit reasonable behaviour given the nature of the system to be modelled, and should meet the expectations of a suitably qualified engineer

As validation is described explicitly, the modelling standard prescribes the components needed to ensure good description of validation. These are listed in the context of the validation referent and classification in Table 3.

TABLE.3 – *Components of the validation referent and classification of a model*

REFERENT	**CLASSIFICATION**
Specify the component to be validated.	Record the component that was validated.
Specify any signals that should be predicted by the model.	Record the signals predicted by the model, for which plant data is available.
Specify error bounds for comparing measured and predicted signals.	Record the error between the predicted and measured signals.
Specify the fidelity of the validation in each case.	Record the fidelity for which the comparison is valid in each case.
Specify the initial conditions, and operating scenario.	Record the initial conditions, and operating scenario.
Specify any anticipated limitations of the validation.	Record any limitations of the validation.

There is an important distinction between the fidelity of the validated signals, and the fidelity of the validation process. For example, a high fidelity signal may only require low fidelity validation. The consideration of the fidelity of a validation process leads naturally to the specification of a range of frequencies of interest for which validation must be achieved.

The limitations of a validation exercise are at least as important as the achievements. Such limitations may result from the nature of the available plant instrumentation, or may be a function of the anticipated operating range of the plant.

Note that the referent and classification are directly analogous to each other, and therefore facilitate direct comparison of the requirements and capabilities of a model. Furthermore the validation status of any existing model may be classified, to provide a comprehensive description of the capabilities of such models.

Validation is one of the most contentious issues in the development of models. It is difficult to describe and difficult to achieve. Yet validation is often key to the credibility of a model. The success of any validation activity ultimately depends on the quantity and quality of plant data that is available. Such plant data may come from the system that is represented by the model, or even from another model whose output is trusted.

WORKED EXAMPLE

Purpose

A hypothetical model has been conceived to illustrate the application of the proposed modelling standard. The purpose of the model is to investigate the responses to transient demands of a marine power system comprising two parallel prime movers and two parallel loads. The prime movers in question share real and reactive power. Stability problems have been encountered, especially in the face of large load impacts. The ultimate aim of the model is to replicate and investigate this problematic behaviour of the system.

Fidelity referent

The fidelity referent is presented in Table 4, and is specified in terms of the phenomena of interest.

Table.4 – *Fidelity referent table*

LEVEL	REQUIREMENT
Very High	None.
High	Alternator subtransient (and transient) response – up to 1kHz. Voltage regulation – up to 1kHz.
Medium	Observation of system 3-phase voltages and currents – up to 65Hz.
Low	Diesel Generator dynamic response to transient load – up to 10Hz. Real and reactive load sharing – up to 10Hz. Frequency regulation – up to 10Hz.
Very Low	Fuel consumption during scenario – steady state calculation.

In this case it is easy to see how each of the fidelity requirements support the stated purpose of the model:

- The subtransient (and transient) response of the alternator is important in the analysis of voltage regulation.
- Voltage and frequency regulation is critical to maintaining system stability in the face of transient demands.
- Observation of Diesel Generator dynamic response to transient load supports investigation of system stability.
- Observation of real and reactive load sharing facilitates investigation of parallel interactions of the Diesel Generator sets.
- The medium fidelity requirement implies that the implementation of any distribution network should include 3-phase busses and cables.

The high, medium and low fidelity requirements relate clearly to the stated purpose, although none of the fidelity requirements are listed in the purpose stated above. Therefore the fidelity referent augments the stated purpose, and specifies the requirements the model must fulfil if it is to support the stated purpose. The process of formulation of the referent is analogous to the decomposition of user requirements into system requirements for a real platform.

The very low fidelity requirement for calculation of fuel consumption does not support system stability investigation. Therefore this requirement could be omitted, with no detriment to the ability of the model to fulfil its purpose. The process of formulating the referent has highlighted this extraneous requirement – a good example of how the proposed modelling standard not only formalizes the process of requirements specification, but also provides input to that process. The very low fidelity requirement will remain in the referent for this hypothetical example, for the purposes of illustration.

Validation referent

The validation referent is presented in Table 5, and forms a detailed description of the requirements necessary to fulfil the intended purpose of the model.

TABLE.5 – *Validation referent table*

LEVEL	REQUIREMENT
Specified	System RMS voltage predictions, up to frequencies of 1kHz: • To within 5% in transient conditions. • To within 1% in steady state conditions. System RMS current predictions, up to frequencies of 1kHz: • To within 10% in transient conditions. • To within 5% in steady state conditions. System frequency predictions, up to frequencies of 10Hz: • To within 5% in transient conditions. • To within 1% in steady state conditions. The transition between steady state and transient conditions is the point at which the plant signal crosses the steady state error bound for validation.

The validation referent itemizes the signals that should be predicted by the model. For each signal, the following details are specified:

- Frequency range of interest – in this case all frequencies associated with stability phenomena.
- An indication of scenario – transient or steady state.
- Error bounds.

The specified frequency ranges correspond to the bandwidth of the respective control loops within the system. This is essential to investigate system stability issues. Note that RMS voltage and currents have been specified for validation – the prediction of 3-phase waveforms is not required for system stability analysis.

In this case the error bounds are relative – they could equally well be absolute. The error bounds have been chosen to reflect the fact that steady state validation is much easier than transient validation.

As with the fidelity referent it is clear that the validation requirements relate to the stated purpose. However none of the validation requirements are actually listed in the purpose stated above. Therefore the validation referent augments the stated purpose, and specifies the requirements the model must fulfil if it is to support the stated purpose. The process of formulating the referents for both fidelity and validation has raised many important questions regarding the detailed requirements of the model. The proposed standard ensures that such questions are raised much earlier in the process of model acquisition that would have been the case previously.

THE MODEL

A hypothetical model was duly developed using MATLAB, Simulink, and the SimPowerSystems Blockset. The proposed modelling standard is sufficiently portable to be applicable to any modelling environment.

Fidelity classification

Table 6 compares the fidelity requirements of the model, as described in the referent, to the capabilities of the model that was developed. Comments in bold highlight deficiency of the model.

TABLE.6 – *Fidelity classification table*

LEVEL	REFERENT	CLASSIFICATION
High Fidelity	Alternator subtransient (and transient) response.	Alternator implemented using substransient circuit equations, in the rotating frame of reference.
High Fidelity	Voltage regulation.	Explicit model of voltage regulator included, together with all dynamic elements.
Medium Fidelity	Observation of system 3-phase voltages and currents.	All components implemented are in fact of medium fidelity, and therefore fully support observation of system frequency within signals.
Low Fidelity	Diesel Generator dynamic response to transient load.	The dynamic response of the Diesel Generators is visible within the results, and is controlled in the model using governors and voltage regulators.
Low Fidelity	Real and reactive load sharing.	This is facilitated by the chosen control strategies for the Diesel Generators – frequency droop for speed control, and quadrature droop for voltage control.
Low Fidelity	Voltage and frequency regulation.	This is facilitated through explicit representation of the governors and voltage regulators of each Diesel Generator set.
Very Low Fidelity	Fuel consumption during scenario.	**NOT implemented.**

The model fulfils all but one of the stated requirements.

Validation classification

Table 7 compares the validation requirements of the model, as described in the referent, to the capabilities of the model that was developed. Comments in bold highlight deficiency of the model.

TABLE.7 – *Validation classification table*

LEVEL	REQUIREMENT	CLASSIFICATION
Specified	System voltage predictions, up to frequencies of 10Hz: • To within 5% in transient conditions. • To within 1% in steady state conditions.	System voltage predictions, up to frequencies of 1kHz: • Predictions accurate to within 4%. • **Predictions accurate to within 2%.**
	System current predictions, up to frequencies of 10Hz: • To within 10% in transient conditions. • To within 5% in steady state conditions.	System current predictions, up to frequencies of 1kHz: • Predictions accurate to within 7%. • Predictions accurate to within 3%.
	System frequency predictions, up to frequencies of 10Hz: • To within 5% in transient conditions. • To within 1% in steady state conditions.	System frequency predictions, up to frequencies of 10Hz: • **Predictions accurate to within 10%.** • Predictions accurate to within 0.7%.

The model fails to meet two of its stated requirements.

Comment

The hypothetical model did not meet its specified requirements, and is therefore not fully fit for purpose. The structured format of the proposed modelling standard highlights specific deficiencies of the model, with respect to specific requirements of the model. Furthermore the capabilities and limitations of the model are described in the same structured format.

The framework is sufficiently unambiguous that all stakeholders can immediately understand what has been achieved, and what has not been achieved. It remains the responsibility of the stakeholders to decide if the model is fit enough for purpose to be acceptable. Thus the proposed modelling standard informs the process of assessment, and ultimately acceptance of any modelling and simulation activity.

Summary

The proposed modelling standard provides a formal, unambiguous means of describing the requirements and capabilities of a model. The requirements and capabilities of a model may be compared directly, to highlight any deficiency within the model. Therefore the proposed modelling standard will inform the acquisition cycle at two key milestones:

- Definition of requirements (including contractual negotiation).
- Assessment and acceptance of deliverables.

Two aspects of the quality of a model, fidelity and validation, have been used to illustrate the proposed modelling standard. The proposed standard includes many such aspects of the quality of a model, as suggested by the keywords of the glossary listed in Table 1.

Therefore the proposed modelling standard has the potential to provide much needed structure to the acquisition process for modelling and simulation activity. This acquisition process can now be coherent and objective, and facilitate a greater integration of modelling and simulation activity with the design process for future platforms. The proposed standard will not guarantee a pain free acquisition process for modelling and simulation activity – rather the proposed standard will provide vital input at project conception and specification, and at assessment and acceptance of the delivered model.

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