A unified model of the electrical power network

Conference or Workshop Item

A Unified Model of the Electrical Power Network

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ABSTRACT

Traditionally, the different infrastructure layers, technologies and management activities associated with the design, control and protection operation of the Electrical Power Systems have been supported by numerous independent models of the real world network. As a result of increasing competition in this sector, however, the integration of technologies in the network and the coordination of complex management processes have become of vital importance for all electrical power companies.

The aim of the research outlined in this paper is to develop a single network model which will unify the generation, transmission and distribution infrastructure layers and the various alternative implementation technologies. This 'unified model' approach can support ,for example, network fault, reliability and performance analysis. This paper introduces the basic network structures, describes an object-oriented modelling approach and outlines possible applications of the unified model.

1. INTRODUCTION

The increasing availability of high performance relatively low cost computers in recent years has presented exciting new opportunities for power utilities to use advanced computer based modelling, system analysis and optimisation strategies for the management of systems. These have ranged from expert system methodologies, neural networks to the application of object oriented methods to power networks covering switching operations, protection, restoration, fault-diagnosis (for remote monitoring and maintenance), reliability and the integration of advanced Energy Management Systems (EMS) -- which are dependent on the effective communication and coordination of vast quantities of network state information. Advances in high performance communication systems, LANs, enable large complex systems to be effectively integrated for the purpose of control and monitoring.

Major network management activities in an electrical power system networks rely upon information relating to the state of the network, which is defined by the network element states and their interconnection. The effectiveness of network management is dependent upon a network model which should closely resemble the real world.

The growing number of customers and the various supporting technologies has resulted in large and extremely complex networks. In the past, system administrators and planners had an overview of the technological criteria for the design, expansion and maintenance of the network. However, it is now much more difficult to manage these tasks because of the greater network complexity and the increasing amount of data to be processed.

To operate successfully in the present competitive electrical supply sector it is desirable to have a totally integrated management system for the network. The aim of the research described in this paper is to develop a software system which will accurately represent the state of the complete electrical supply network, integrating technical managerial, operational and control factors.

As electricity supply is a dynamic sector, it is essential that the network model under development be representative and easy to maintain and extend. It was decided to use object-oriented techniques for the development of a unified network model; the resulting model being implemented in a database system. Graham [1] and Jacobson et al [2] argue that these methods result in flexible systems, providing good support for future change and in this respect are much better than the more traditional analysis, design and modelling methods.

2. ELECTRICAL POWER NETWORK

Power companies operate large regional or nation-wide electrical power networks often with millions of customers all having diverse requirements. Normally, national electrical power systems are organised into generation, transmission and distribution networks. This section briefly describes typical schematic electrical network structures, technologies and services. More detailed descriptions can be found in Say [6], Ryan [7], Weedy [8], Robert et al [9] and relevant CIGRE / IEEE / IEE publication.

A network can be described completely in terms of technology and topology. Currently, there are three basic network topologies employed in the electrical network: star, tree and ring (or mesh).

Figure 1 shows a simplified representation of a typical electrical power system structure. As is well known a local power station serves one area which can be subdivided into several districts. These districts are connected to the local power station via substations. Power supply lines branch out from the power station to the customer via a tree-like structure incorporating different types of sub stations. A number of large industrial customers have dedicated power supply lines running from their premises to the power station.

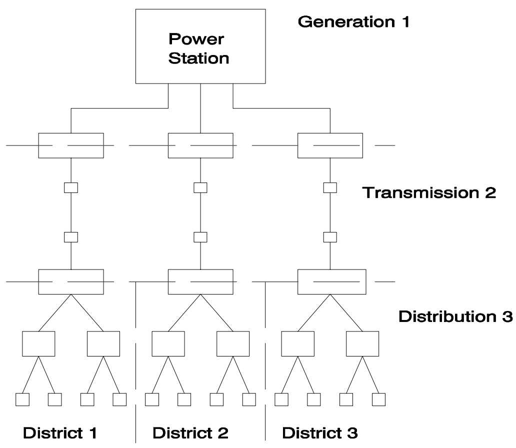

Fig. 1 Simplified power system structure with generation, transmission and distribution elements.

Special customers, such as hospitals, must have a highly reliable electrical power supply to maintain their activities. Additionally, to provide electrical supply in the event of a failure such organisations usually have reliable backup power supply systems. These backup systems often employ diesel generators or large battery banks and inverters.

A typical simplified object schematic of a electrical power generation system is shown in Figure 2a, where the electrical equipment is represented by node objects connected together by link objects. Corresponding examples of power transmission and distribution systems are shown in Figure 2 b and c respectively.

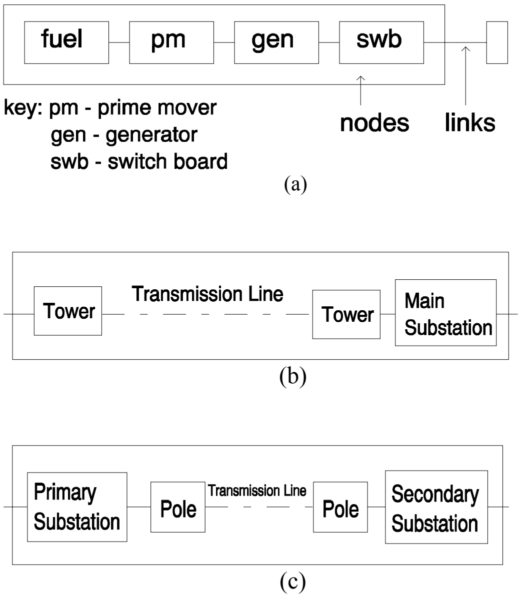

Fig. 2 : Object Schematic diagrams of a simplified Power system.
(a) Power Generation;
(b) Transmission;
(c) Distribution.

3. OBJECT-ORIENTED MODELLING

The object-oriented concept enables the development of flexible and intuitive models. This section introduces the basic principles and for more detailed discussions see Graham [1], Jacobson et al [2], and Rumbaugh et al [4]. Object-oriented modelling is based upon the organisational principles of human thought processes:

- Classification (abstraction)
- Inheritance (generalisation/specification)
- Association
- Aggregation (whole/part-structure).

These principles are applied to create a model.

Classification
To create a model, the problem domain is analysed to identify classes of relevant real world objects. Classification is the operation of grouping together objects with similar features. Once the classes have been determined, it is necessary to identify the relationships between them. Individual instances which belong to the respective classes are called objects. Objects can represent physical items such as a copper cable or abstract concepts, such as a packet of data in an instrumentation and monitoring system. Each class of objects is characterised by its static and dynamic features. The static features are called attributes of a class and the dynamic features are called the methods. All objects of one class have the same attributes and methods, but each individual object may have different attribute values. However, each object has an individual identity even if other objects of the same class have identical attribute values.

Inheritance
If there are specialised types of a class which exhibit common features, the principle of inheritance can be used to organise them. The specialised classes are called sub-classes and contain only the features which distinguish them from the other specialised classes. The respective sub-classes inherit all the common features contained in the super-class. For example, if transformer is considered to be a super-class, specialised transformers such as voltage and current types would in turn be sub-classes. The transformer super-class would contain features such as power rating, common to all sub-classes. However, the sub-classes would in addition contain their own particular attributes and functions, relating to special factors, for example, insulation type, output voltage accuracy and safety/monitoring features.

Association
In the context of object-oriented modelling, association represents a relationship between two different classes of objects. For example, if a power supply is connected to an instrumentation device, this relationship can be modelled by an association between the power supply class and the class of instrumentation equipment.

Aggregation
An aggregation expresses a special relationship between classes of objects in which one class contains the other class. Composite objects built from several component parts are shown as aggregations in an object-oriented model. For example, a switch board (SWB) with many modules components could be modelled as an aggregation, the whole SWB being a composite object with the individual SWB modules as its components.

4. THE UNIFIED MODEL

Individual models and records exist for different network element types and infrastructure layers. Independent records are kept for generation, transmission and distribution equipment. Information relating to, for example, underground duct and cable infrastructures are often held separately. This approach has the following disadvantages:

- Although technologies within the real network are integrated, the existing diverse models are not and as a result network management is difficult.
- Network management activities are not coordinated because of the unconnected models and records.
- Potential data inconsistencies can result from the duplication of information in different records.
- It is not possible to simulate the strategic, and often diverse management activities in order to evaluate their effects on the whole network.

These disadvantages may be attributed to the fact that the separate models and records cannot be combined for management purposes. A unified network model would therefore improve the efficiency of the individual network management applications by integrating and coordinating the various technologies and infrastructure layers. Such an approach has been successfully pursued by the authors in the area of communication networks[5].

All current models are generally ‘tailored’ for specific network management applications and hence represent very specialised abstractions. However, every application is based on the real network. It is therefore possible to build a unified model which supports all applications providing this model is based upon the underlying domain structure. Initial analysis and design need not take into account, to any great extent, the functionality of particular applications. This design philosophy is the basis of object-oriented system modelling. It has been recognised by Graham [1] and Jacobson et al [2] that most software system modifications are associated with system functionality rather than the underlying domain. Hence, a system which is built around the domain entity structure is more stable than one based upon system functionality.

As object-oriented modelling is based upon the organisational principles of human thought processes, it is possible for domain specialists to comment upon the design of the object model. The domain specialists can gain insight into the design of the object model without requiring specialist computer skills.
In an object-oriented model, the object and their associations correspond directly to real world entities and their relationships. As a result, the object model is highly modular and closely resembles

the real network. These characteristics make the model easy to understand, maintain and extend [5].
A major difference between object-oriented modelling and other approaches is the inclusion of the dynamics of a system in the objects. Objects are therefore self-contained structures and the resulting system is highly modular. Modularity significantly enhances the maintainability and extendibility of the system. Further on-going development of the object model is possible, even after it has been installed, because the object schema can be continuously evolved.
These factors, together with the use of CASE-tools (Computer Aided Software Engineering), aid the management of the problem domain's complexity. Detailed analysis of the problem, during the initial stages of the development cycle, promotes the elimination of costly rework during the implementation phase. By developing these techniques, a system is designed which closely matches user requirements.

5. STRUCTURE OF THE MODEL

The basic structure of an electrical power system can be considered to consist essentially of a set of ***nodes*** and ***links***. The node could be a component of a power system, such as a generator, transformer, switchgear etc. A link is a conductor which connects nodes together. Therefore, an overhead transmission line and underground cables etc. could be elements within a link.

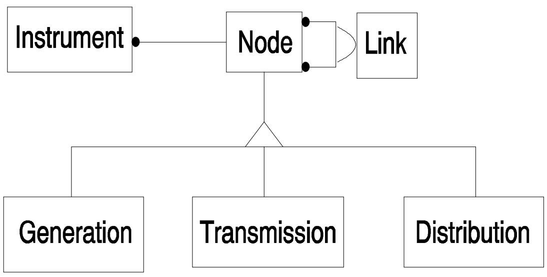

Fig.3 Object diagram of an electrical power network model.

The object diagram of an electrical power network is shown in Figure 3 and Table 1. The class **Node** has an association relation with itself. This means each **Node** object might connect to any other **Node** objects where the connection information is specified by the **Link** class.

A specific example of an electrical power network is shown in Figure 4.

6. UTILISATION OF THE MODEL

The unified model provides an integration platform for the various network management activities. The model is situated at the centre of an overall systems architecture, see Figure 5. It provides the services and stores the essential data for a number of different applications. It is intended that this integrated system will be implemented in a distributed database. A number of important applications which can employ the model include network capacity expansion, network maintenance, reliability analysis and performance analysis.

As the dynamic performance of the whole electrical power network is complex, simulation can provide the best means of evaluating the effects of diverse network management activities. (see Appendix)

Association	(Class 1)	(Class 2)
	Node	**Link**
	Node	**Instrument**

(a) Association

Generalisation	**(Super-class)**	**(Sub-class)**
	Node	**Generation**
		Transmission
		Distribution

(b) Generalisation

Aggregation	**(Whole)**	**(Parts)**
	Generation	**Fuel**
		Prime Mover
		Generator
		Switchgear
		Transformer

(c) Aggregation

Table 1 : Relationship between classes

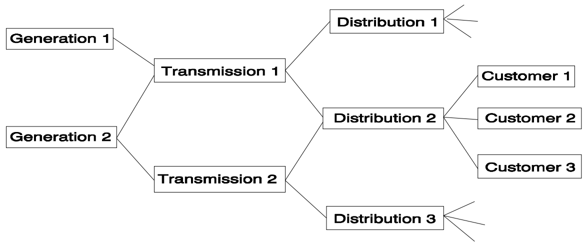

Fig.4 Top level of an electrical power network.

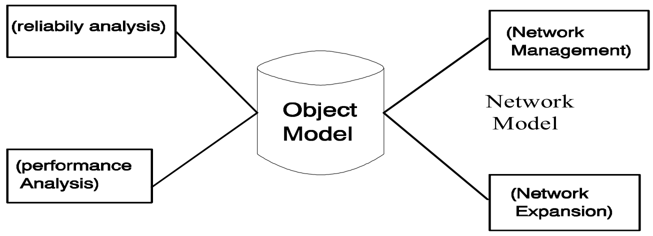

Fig. 5 System Architecture.

7. DISCUSSION

The electrical power system has a complex structure and incorporates a large number of network elements. The development of an accurate integrated network model is therefore a major undertaking. Related research has shown that object-oriented modelling techniques aid the management of the problem domain's complexity and enable improved communication with domain experts.
The authors conclude that all network management activities can benefit from a unified model and it is believed that a unified model would be a major asset for any electrical power company.

The authors will provide an update of progress at the conference supported by case studies. It is anticipated that the unified approach will be capable of handling the wide range of system problems such as the analysis of loading patterns and constraints, plant overloading, ageing, risk management, new protection procedures etc.

Research to date has focused on fault analysis using artificial neural networks (ANNs). The prototype analysis system, used as the initial learning strategy, employs the standard back-propagation algorithm. Current research is being undertaken using evolutionary computing technique (genetic algorithms, GA’s) to significantly improve the performance. GA’s offer very efficient global parallel search capabilities. Investigations are also taking place to evaluate the potential of parallel computer architectures to provide significant improvement in processing rates. It is anticipated that , in the near future, efficient algorithms will be developed , which , used in conjunction with parallel computer architectures, will make it possible to analyse and solve systems of high complexity within reasonable time scales.

APPENDIX

System Operator's View of Evolving Computer Applications

Kennedy [11] in his recent paper, which reviews the application of computer technology to power system management, has been able to summarise the key factors to be considered, see Figures 6 and 7.

Figure 6 illustrates a system operator's view with respect to the amount of improvement the application of digital computer techniques has made to the eight important system operating tasks. It can be seen that the information management task is perceived to be the most enhanced. Tasks which at present are completed without the aid of a computer could in the future be efficiently integrated within a unified computer based management system thereby achieving improved operating results. Kennedy's inclusion of the task 'creation of new ideas' is contentious as at present it is considered that only humans can create new ideas. Kennedy also comments that while operator tasks are routine requiring little or no complicated analysis, most tasks involve decisions which require a combination of deductive, inductive and intuitive reasoning [11].

Brielfy, Figure 7 illustrates a simplistic view by Kennedy [11] of four areas of the system operator's decison strategy domain where the digital computer has been effective in reproducing and even surpassing, human capabilities. Kennedy points out that when viewing Figure 7 it should be remenbered that most operator's decisions usually involve more than one of the four decision strategies. Future advances in high performace relatively low cost computers will undoubtedly result in greater emphasis in the implementation of optimisation techniques to improve system operation with the caveat that rigorous evaluation of software performance is essential to ensure system integrity.

Clearly, the application of information technology (especially networked computers) will allow senior managers to analyse, design and implement advanced models of complex systems for the purpose of optimising a variety of management activities. The present authors consider that their unified approach has great potential in this regard.

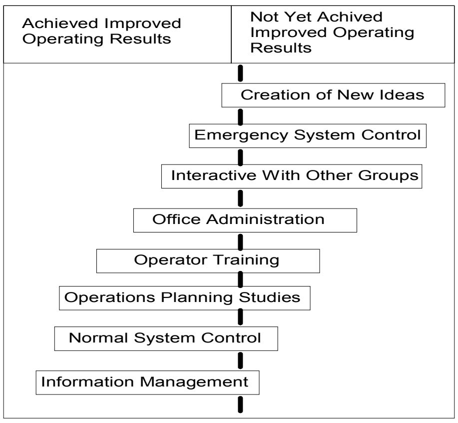

Fig.6 Effectiveness of digital computer operating systems in performing important system operator tasks.[11]

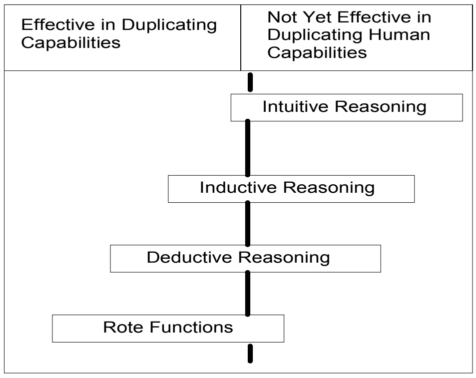

Fig.7 Digital computer's role in duplicating the system operator's decision process.[11]

REFERENCES:

[1] Graham : "Object-Oriented Methods", Addison-Wesley, 1991.

[2] Jacobson, M & Christerson, P & Jonsson, G "Object-Oriented Software Engineering", ACM Press/Addison-Wesley, 1992.

[3] Coleman, P & Arnold, S & Bodoff, C & Dollin, H & Gilchrist, F & Hayes, P : "Object-Oriented Development", Prentice-Hall, 1994.

[4] Rumbaugh, M & Blaha, W & Premerlani, F & Eddy, W : "Object-Oriented Modeling and Design", Prentice-Hall, 1991.

[5] Paul, H. & Tindle, J. & Woeste, C : "A Unified Model for the Local Access Network", 1994

[6] Say M G : "Electrical Engineer's Reference Book", Butterworths, 1973.

[7] Ryan H M, Editor "High Voltage Engineering and Testing", IEE Peregrinus Ltd, 1994.

[8] Weedy B M : "Electric Power Systems", John Wiley & sons, 1987.

[9] Eaton J R & Cohen E : "Electric Power Transmission Systems", Prentice-Hall, 1983.

[10] British Electricity International, London, "Modern Power Station Practice", Pergamon Press, 1991.

[11] Kennedy T., 'A System operator's View of Evolving Applications' IEEE Computer Applications in Power , Vol 8 , No2 , pp25-29 , April 1995.

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