INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 01 GLASGOW, AUGUST 21-23, 2001

DEKAS - AN EVOLUTIONARY CASE-BASED REASONING SYSTEM TO SUPPORT PROTECTION SCHEME DESIGN

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Keywords: Expert Systems, Case-Based Reasoning, Web-based Systems, Knowledge Acquisition, Knowledge Representation, Design Re-use, Best Practice

1 Introduction

This paper describes a decision support system being developed in conjunction with two UK utility companies to aid the design of electrical power transmission protection systems. A brief overview of the application domain is provided, followed by a description of the work carried out to date concerning the development and deployment of the Design Engineering Knowledge Application System (DEKAS). The paper then discusses the provision of intelligent decision support to the design engineer through the application of case-based reasoning (CBR). The key benefits from this will be outlined in conjunction with a relevant case study.

2 Overview of Protection Scheme Design

The electricity transmission grid transports electricity from the generators (e.g. power stations) to the distribution companies at high voltages. The voltage is then "stepped-down" to supply electricity to consumers via distribution networks. There is a requirement to protect the network and associated equipment from possible damage arising from faults on the transmission and distribution networks. The transmission network is composed of large numbers of expensive plant items, and a fault on the transmission network may also lead to a widespread power outage affecting thousands of customers over a large geographic area. In order to minimise the damage to transmission plant and the extent of any outages, protection schemes associated with transmission networks are generally more complex than those associated with distribution networks. This work focuses on the provision of intelligent decision support to protection engineers during the design of protection schemes for electrical power transmission networks.

The protection design is dependant upon several factors including, the topology of the network requiring protection, the primary plant type and layout and the interfaces to existing protection schemes in the surrounding area of the grid. Each protection scheme design conforms to fundamental protection principles applied in conjunction with standard company procedures [1]. A common starting point for a protection engineer when confronted with the task of designing a ‘new’ protection scheme, is to assess the general protection requirements of the section of transmission network and associated primary plant to be protected. This usually involves the identification of past similar protection scheme designs from which specific features of the design may be re-used and lessons learned applied. Typically, protection engineers will rely upon their own experience, or possibly that of a colleague when attempting to re-use design knowledge. In addition engineers will draw upon various references such as company standards, repositories containing network details and other relevant company resources.

3 The Requirement for Decision Support within the Existing Protection Design Process

The provision of decision support for engineers involved in the protection design process aims to foster a more co-operative and consistent approach to protection scheme design, through the promotion of 'best practices' [2]. This can be achieved by:

- Providing a single, 'virtual' source of information for the engineer to draw upon during the design process. Throughout this process there are many different documents, standards and databases which the engineer requires in order to successfully complete the design of a protection scheme. These are stored in both paper and electronic formats, and in a number of different locations. As a result, presently during the design process a disproportionate amount of time and effort is invested in the search and retrieval of relevant information required to perform the various design activities.

- Harnessing and leveraging the knowledge and experience of protection engineers, accrued over a number of years service within the industry, as a valuable company asset and resource. This also addresses the risk associated with the loss of knowledge and expertise associated with individuals departing the organisation.

- Promoting the sharing, dissemination and re-use of knowledge throughout the organisation. This is of particular value to engineers with limited design experience, where they may benefit directly from the lessons learned and knowledge captured from their more experienced peers.

- Exploiting existing historical design data and information associated with past protection scheme design projects.

4 Existing DEKAS Functionality and Architecture

4.1 The DEKAS Design Process Knowledge Models

The protection design process associated with each company was captured through an extensive series of knowledge elicitation sessions conducted with protection design experts from each company [3]. The captured design process knowledge was then represented graphically using the 'task' and 'inference' layers of the KADS knowledge modelling methodology [4]. These knowledge models illustrate the interaction between the various design process activities through their associated data and information flows. This process knowledge has been encoded within DEKAS using standard database and web (front-end) technology, and deployed via existing company intranets [5].

4.2 Integration of DEKAS with Existing Company Resources

As a design project progresses, the DEKAS web front-end can be used to navigate the design engineer through the various stages of the design process. DEKAS consists of a database containing links to existing company data and information repositories and resources, providing the engineer with access to all relevant data, information and documentation necessary to successfully perform the current design activity. These resources can be accessed through an 'information' layer, which provides supporting information relating to the use of a particular resource or a list of pertinent questions to be asked of a particular individual, (note that a resource may be defined as a document, database, spreadsheet or a liasing individual).

An electronic file structure exists, encouraging all documents produced as part of a particular design project to be stored in a single, structured format. This document storage facility previously existed as a paper based equivalent. Although DEKAS does not profess to be a document management system, however in the absence of a proprietary document management system some extent of organised structure for document storage is required. This enables effective retrieval of relevant documentation via the links on the navigable web pages, and the CBR facility (discussed later). Integration with an 'off the shelf' document management system at a future date remains a possibility.

5 Intelligent Decision Support Provided by DEKAS

The decision support feature of DEKAS will be greatly enhanced through the incorporation of intelligent Case-Based Reasoning (CBR) functionality. This emulates existing work practices, which draw upon past experiences and lessons learned to derive the most appropriate 'solution' for a particular 'problem'.

5.1 Role of CBR within DEKAS

A CBR system typically consists of a library of cases (or a case base), where each case is represented by a case structure described by a number of predefined indexing parameters. These indexing parameters can then be utilised by the CBR algorithm to assess the similarity between individual cases as part of the CBR retrieval process. At the highest level, the CBR cycle is described in terms of the following processes [6]:

- RETRIEVAL of the most similar case/s.
- RE-USE of data, information and ultimately knowledge associated with the retrieved case, to solve the current 'problem'.
- REVISION of the proposed solution to meet the specific requirements of the current 'problem'.
- RETENTION of the 'new' case and associated solution for future application within the CBR cycle.

This cycle effectively emulates the intuitive reasoning process adopted by protection design engineers at the inception of a design project. At present, knowledge of previous design solutions are restricted to, and reliant upon, the experience of individual engineers. Therefore re-use of previous design knowledge and rationale requires engineers with extensive design experience to participate in the protection design process.

The introduction of the CBR facility within DEKAS is intended to broaden and maintain the knowledge base available to design engineers within the organisation. This is achieved by consolidating individual experiences within a continually expanding case library. For each completed design project, the solutions applied and lessons learned are made accessible to all engineers through the application of case-based reasoning techniques within the existing DEKAS framework. The incorporation of CBR functionality within DEKAS will promote a more formal approach to the retention and dissemination of experiential design knowledge within each organisation.

5.2 Design of the Case-Based Reasoning Functionality

Definition of the Nested Case Structure

The topology of an area of transmission network and the primary plant configuration largely dictates the design of its associated protection scheme [1]. Therefore, network areas of 'similar' topology and plant layout will generally share 'similar' protection requirements. A basis for the comparison of different areas of transmission network, associated with current and previous protection scheme design projects, is necessary to establish any inherent similarity between the two. This basis for comparison requires characterisation of the network area through a comprehensive list of indexing parameters, which effectively constitute the case structure. The indexing parameters identified must be comparable across all cases and contribute directly to the matching process, i.e. they must have some degree of influence on determining how similar one case is to another.

The construction of the case structure reflects the physical construction and topology of the transmission network it describes. Figure 1 illustrates the nested relationship of the case structures intended to describe an area of network, which is the subject of a protection design project. Each 'sub-case' structure represents a physical feature of the network (i.e. Substation, Bay, Plant, Line, etc.) which may itself be described in terms of a number of indexing parameters. In addition, each sub-case structure effectively represents an indexing parameter of the higher level case structure in which it is embedded. Arranging the case structure in this way allows each indexing parameter to be placed in the context of the various network features they describe. This in turn facilitates the matching of the design project on different levels of detail (i.e. project level, substation level, bay level, equipment level), without the requirement for separate case bases. The nested case structure arrangement enables a single case base to be implemented, eliminating unnecessary duplication of indexing parameters within different cases, and providing the flexibility required to accommodate the varying number of substations, substation bays and plant items contained within the network area requiring protection.

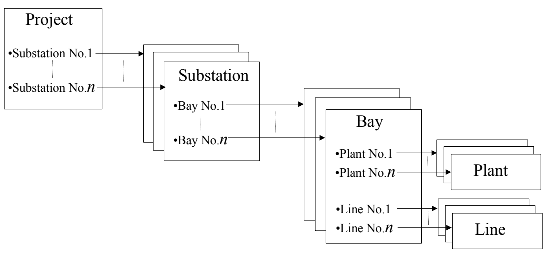

Figure 1. Nested Case Structure

Definition of the Weightings and Similarities

The 'degree of influence' a particular indexing parameter has in calculating the 'overall' similarity between two independent cases can be defined by the cumulative effect of the weighting and similarity values associated with the indexing parameter itself and indexing parameter value respectively. The contribution of the weightings and similarities attached to the complete set of indexing parameters detailed within the case structure, are combined through the implementation of the nearest neighbour algorithm. This provides an overall assessment of the similarity between the network areas associated with a current and previous protection design project.

The roles of weightings and similarities in CBR are well documented [6]. The weightings and similarities applied within the DEKAS case-based reasoning facility have been derived through knowledge elicitation sessions with design experts. During the protection design process the impact of each indexing parameter on the determination of the 'most similar' previous case (i.e. protection design project) through the CBR matching process, will vary depending upon the current stage or activity of the design process. In instances where the indexing parameter makes no contribution to the overall similarity assessment, the weighting value associated with that parameter will be zero. Therefore, each indexing parameter must have associated with it, a separate weighting value relating to, and defined by each activity within the overall design process. The weighting attached to each indexing parameter can then be automatically adjusted to a predefined value, depending upon the stage/activity of the design process at which the CBR facility is invoked. Adjustment of the weightings in this manner is more representative of the intuitive approach currently adopted by engineers, than a CBR system implementing a static set of weightings neglecting the changing task objectives throughout the design process [7].

Integration of CBR with Modelled Design Process

As previously described, the CBR functionality of DEKAS is responsible for the identification of similar protection designs of the past. However, using CBR to return all data, information and documentation associated with a previous design at the beginning of a current design, is unlikely to be the most effective implementation of the CBR functionality for two main reasons. Firstly, at the beginning of the design process the current 'project' case (Figure 1) may be incomplete, with some indexing parameters only becoming available at later stages. Therefore, retrieved design documentation associated with other stages of the design process, not yet encountered by the engineer, may be less relevant. Secondly, providing the design engineer with all project documentation risks overloading the engineer.

It is for the reasons described that an evolutionary approach, dependent upon the current stage of the design process, is adopted for the population of a particular case and the return of relevant design information (Figure 2). Therefore, as the design progresses, more information becomes available which can be used to populate the 'empty' indexing parameters describing the current design case. This evolving case description enables constant refinement of the CBR search as the design engineer progresses through the modelled design process. In addition, only information associated with the similar case identified and relevant to the design activity currently being performed by the design engineer is retrieved (e.g. an engineer performing the "produce technical specification" design activity will have the 'specification' document of the 'most similar' previous design project returned).

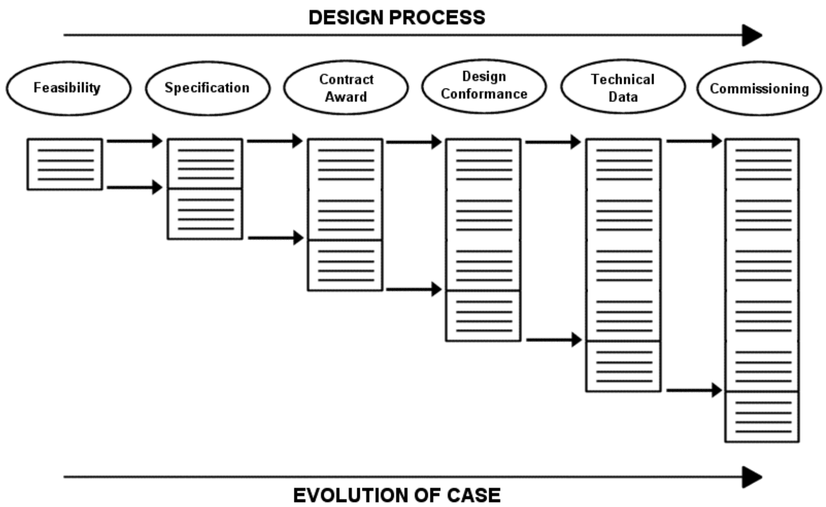

Figure 2. Evolution of Case with Design Process

Consolidation of Lessons Learned for Re-use of Design Solutions

Often as an engineer progresses through a 'new' protection design, they are confronted with fresh challenges and problems, which may require an equally novel approach to derive a suitable solution. While the success of a particular design solution may vary, the ensuing lessons learned are always valuable. DEKAS provides the design engineer with the opportunity to formally document any specific 'lessons learned' associated with the various design process activities performed during a particular project. The CBR facility within DEKAS then offers engineers facing similar problems the opportunity to benefit from the experiences of their peers, by first alerting them to potential design problems and returning the associated lessons learned. This enables the engineer to either directly re-apply or refine and apply a previous solution to a specific design 'problem'.

6 Case Study - Using DEKAS to support the Design Process

This case study illustrates the use of DEKAS to support a protection engineer throughout the protection design process from start to finish. When presented with a 'new' protection design project, the design engineer's first activity is to launch DEKAS and register the project. This creates an electronic design file providing a designated location for the electronic storage of all future documentation created during the design process. The next stage is to navigate from the high level task model down to the appropriate design activity. Contained within the model of the current activity, are links to relevant information sources required to complete the activity. The output from this stage may be to create a particular document.

This document conforms to a standard structure where information contained within it relates directly to the indexing parameters of the case structure. The automatic extraction of the indexing parameter values from the project documentation is transparent to the user, and avoids the need to explicitly populate the case structure, minimising duplication of effort. Once an activity has been completed and the output document stored in the electronic design file, the engineer can then navigate to the next activity within the modelled design process. In addition, links to project specific information including documents produced as a result of the previous design activity may also be provided. This is particularly useful when multiple design engineers are involved in the design or a change of design personnel occurs during a project. This provides engineers with direct access to design documentation produced by other members of the design team.

Where some of the indexing parameters for the current design have already been populated (from a previous activity) the CBR function can then calculate the most similar previous case(s) to the current design. Through the derivation of this model, it has been identified that a further useful source of information would be to consider technical specifications from similar designs. The current model has identified the type of document required, in this case the technical specification. This, combined with the CBR which has identified the most similar project, provides access to a similar technical specification stored in the relevant electronic design file. As the engineer proceeds through each design activity, more indexing parameters become known and the associated weightings will adjust such that relevant documents from another previous design project may be retrieved.

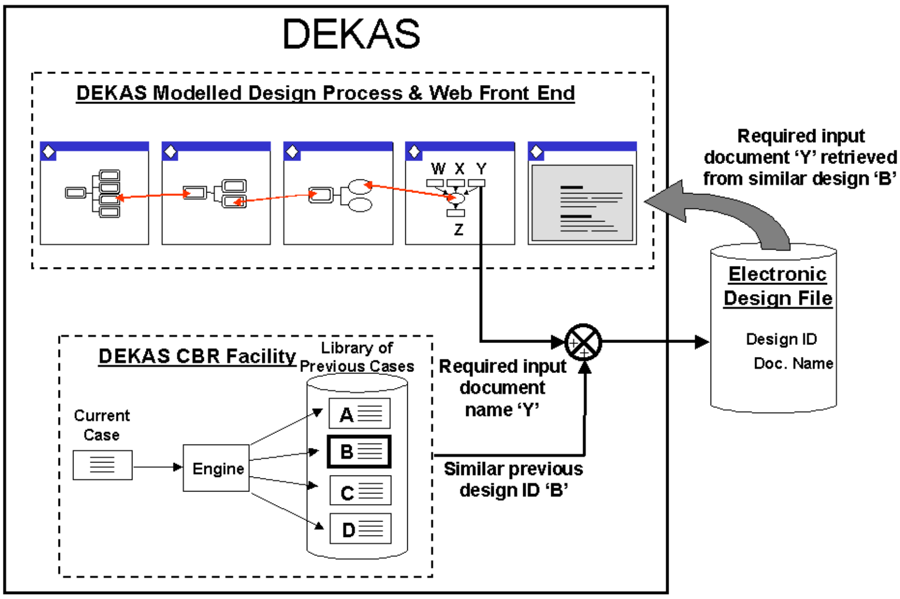

Figure 3. DEKAS Architecture

7 Conclusion

This paper describes the application of case-based reasoning techniques in the provision of intelligent decision support for protection scheme design engineers exhibiting varying levels of technical experience. The system effectively provides the user with knowledge and understanding of the practical constraints, commonly occurring problems, idiosyncrasies and lessons learned encountered during previous designs, and the subsequent design solutions applied.

The design of a protection scheme from 'first principles' is a complex task involving the consideration of multiple constraints and inputs in conjunction with a comprehensive knowledge of protection design principles. Although circumstances may exist which dictate a protection scheme should be designed in this manner, adopting this as a standard approach on a day to day basis would generally prove impractical in terms of the time and effort required. Also, in view of the repetitive nature of the design process, and to a large extent the design solutions applied, the requirement for bespoke protection scheme design is often unnecessary.

This is particularly evident from the current method of protection scheme design which relies predominantly on the engineer's capacity for recalling previously designed schemes which exhibit similar protection requirements to that of the current design project.

While other artificial intelligence techniques may provide some form of intelligent decision support (e.g. rule-based, model-based systems), these may be more aligned with a design approach from 'first principles'. In contrast, the existing design approach concentrating on the re-use of available design knowledge appears more predisposed to the application of case-based reasoning.

This paper illustrates how case-based reasoning functionality can provide more effective and relevant output (i.e. decision support) when placed in the context of the individual design process activities [7]. The evolution of the case structure and the adjustment of associated weightings, driven by the design process activity, combine to present the engineer with the 'most pertinent' information from the 'most similar' design project contained in the case library. DEKAS therefore offers design engineers access to the right information at the right time throughout the design process, and promotes the sharing of valuable engineering experience retained within a constantly expanding case base.

8 Acknowledgements

The authors gratefully acknowledge the contributions of ScottishPower, and National Grid Company, to the work described within this paper.

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