Reuse of an ontology in an electrical distribution network domain[1]

Hercules Dalianis ‡ **Fredrik Persson** ¥

‡Department of Computer and Systems Sciences
The Royal Institute of Technology and Stockholm University
Electrum 230, 164 40 Kista, SWEDEN
ph. (+46) 8 16 49 16, mob ph. (+46) 70 568 13 59
E-mail: hercules@dsv.su.se

‡Cap Gemini
Box 825, 161 24 Bromma, Sweden, ph (+46) 8 704 50 00
E-mail: hercules.dalianis@capgemini.se

¥ JP Bank
World Trade Center, 107 81 Stockholm, Sweden, ph (+46) 8 700 47 64
E-mail: fredrik.persson@jpbank.se

Abstract

Reuse of knowledge from one domain when modelling new domains is a human task. But what happens if one does this task in a more principled way? In this paper we present the use of the results from an ESPRIT project called KACTUS on a real case where we modelled an electrical distribution network with support from a library of ontologies describing various technical domains. In this library we found descriptions of electrical transmission networks and we decided to use these for the modelling of the distribution networks of the Swedish utility company Sydkraft. The results was that the main part of the concepts in the ontology was possible to reuse except some very domain specific concepts. The whole knowledge acquisition phase was carried out in 4-5 days. The conclusion was that the KACTUS approach in the knowledge acquisition process was extremely fast and accurate.

Introduction

The knowledge acquisition phase during expert system development can be very time consuming and inaccurate. Therefore would it be valuable to have some method to make it easier speed up the knowledge acquisition phase by some sort of reuse of previously developed systems. In the KACTUS (modelling **K**nowledge **A**bout **C**omplex **T**echnical systems for multiple **US**e) ESPRIT Project P8145, a method, a tool, and a ontology library (see http://www.swi.psy.uva.nl/projects/NewKACTUS/library/library.html) , have been developed to make it easier to construct knowledge based systems for complex technical domains. The knowledge about technical systems stored in the library are called ontologies.

One problem with reuse is the cost to develop such systems. Therefore would it also valuable to have a standard method and language to develope an expert system and that the conceptual model of the system is stored in one library from where it later can be reused.

The Artificial Intelligence community use the concept of ontology to describe a hierarchical conceptual model which contents range from very general concepts to very domain specific concepts. In this paper we use also the concept of ontology.

Sydkraft, an electrical power company in the south of Sweden wants to build a computer system for the minimization of losses in the distribution networks. To carry out this tasks they first needed to model their distribution network. There we stepped in to help them.

Previous research

One of the first investigations in the reuse area is found in (Biggerstaff and Richter 1987) where different possibilities and approaches is discussed of reusing different components in software development. In (Maiden and Sutcliffe 1992) we find a description of domain abstraction and the mapping to a new domain. (Neches et al 1991) discuss the sharing, reuse and extending of knowledge bases. They point on four bottlenecks in sharing and reuse and propose a solution to overcome them. (Gruber 1993)

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[1] This work was carried while the authors were working at the KACTUS project at Cap Gemini (Former Cap Programator)

investigates the sharing and reuse of ontologies over domains and representation languages. (Wielinga and Schreiber 1994) discusses the separation of knowledge in various layers in a ontology to permit resuse of the ontologies.

In the KACTUS project we have modelled three technical domains: Electrical Transmission Networks (Fault Diagnosis and Service Recovery Planning) , Oil Production and Processes and Mid Ship Section Design and Assessment. These threes domains have been used for building and abstracting the ontology library. In the Electrical Transmission Networks domain presented in (Bernaras and Laresgoiti 1996) the authors has showed how two ontologies: Fault Diagnosis and Service Recovery Planning respectively have been integrated into one since there where overlapping/redundant information in the two ontologies. The overlapping part happened to be the Structural Ontology i.e. the part which described the structure of the Electrical Transmission Network. The modelling language used for the Electrical domain has been CML (Schreiber et al 1994), developed in the Common-KADS KADS II, ESPRIT Project P5248.

Reusing the Unified Electrical Network ontologies for a distribution network

One of the main objectives of the KACTUS project was the reuse of knowledge. The ontologies for electrical networks presented in (Bernaras and Laresgoiti 1996) describe transmission networks which, transports electrical power for long distances. An interesting experiment would be to reuse this knowledge for the low-voltage distribution networks, which distributes the electrical power from the transmission network to the consumers. The distribution networks are in many aspects very similar to the transmission networks, however there are some differences in the structure and also some differences in what kind of problems one needs to solve in the two types of networks.

Sydkraft, an electrical power company in the south of Sweden, helped us with the expert knowledge about their distribution networks. As a starting point we identified an interesting problem to keep in mind while doing the modelling, since it is generally well-known that ontologies cannot be specified absolutely application-independent, according to (Ostermayer et al 1995).

We interviewed the experts and recorded the discussions. We showed on overheads the transmission network ontology and asked the experts whether the same components were present in a distribution network. The experts explained for us what the similarities and differences were between distribution and transmission. We met twice all together for a whole day each time and then we needed two-three days at the office to document the work and to use the KACTUS toolkit to create the new ontology from the library.

Optimal distribution system configuration

An interesting problem for Sydkraft is to optimize the distribution system configuration. The goal is to reduce electrical losses in the network. If the network is badly planned, the current has to be transported for long distances which causes big losses. This problem is generally more interesting in distribution networks than in transmission networks, since the big losses occur in the low-voltage networks. In the distribution networks of Sydkraft the losses are 4-7□% and in the transmission networks 1-2□%. On the other hand, the distribution networks are more difficult to control since just a very few components are automatized and remote controlled. This means that changing the network structure might require that a lot of personnel drive around with cars or even walk into forests in order to open or close switches.

There are several ways of reducing the losses. The most obvious one is to change the structure of the network by opening or closing disconnectors. Other ways is to adjust taps in the transformers in order to control the voltage optimally, or to use shunt capacitors to reduce reactive power.

Optimizing the network structure with regard to minimize the losses is partly a mathematical problem and partly an expert system problem. Mathematical optimization theory can help to find the optimal configuration when the parameters are well-known and when the problem is reduced to find the configuration which minimizes the losses[2] with the respect to some simple constraints, such as upper limits on the currents in the lines. When the solution is found, the experts or the expert system need to decide whether it is possible to realize. This judgement include a lot of more “heuristic knowledge“. For example:

- Some switches are very hard to reach, since they are located far away from the roads etc. In this case, try to find another solution close to the optimal one which avoids the hard reached switches.
- Some customers might have special agreements, which for example guarantee them a maximum of 2 hours of power failure per year. Such an agreement affects the optimal configuration since we might want to have a more secure connection to that specific customer. These kinds of agreements will be more common in the future because of the deregulation of the electrical power market in Sweden.
- The expert system should also plan actions to realize the changes of the network. There are a lot more to do than just changing the switches. For example changing the trigger levels for the protective relays.

[2] The losses are the sum ($\sum RI^2$), which means that the problem mathematically can be viewed as a Quadratic Programming problem, with the important and difficult constraint that only “spanning trees“ are allowed as solutions.

With this possible application of optimizing the distribution system configuration in mind we wanted to build ontologies for distribution networks.

Ontology building

For the optimization problem mentioned above, there is a lot of knowledge needed. Here, we have concentrated on the most general knowledge about distribution networks such as the structure of the network, how it is connected and the role of customers. This knowledge should be the most reusable for other applications in the area of distribution networks.

As a guideline for the ontology building we have used (Ostermayer et al 1995). It describes how ontologies should be constructed in order to be reusable. In this case, we have a very good base for the new ontology since the structure of transmission networks are well modelled. The main work has been to verify that the transmission Structural ontology is applicable for distribution networks. That is not the typical situation treated in (Ostermayer et al 1995) but we have tried to use the guidelines wherever it has been possible, especially we have used the Ontology modelling sequence suggested in (Ostermayer et al 1995)

Step 1: Specify the application context and the modelling view

The application context is already described in the section *Optimal distribution system configuration*, above, but we need to formalise it and make sure that we follow all the steps in the modelling sequence.

1.1 The application domain is the domain of Electrical distribution networks.

1.2 Application operations or possible tasks:
Planning of how to configure the network in order to minimize the losses.
Planning of how the protective relays and the breakers should be adjusted after the minimization is done.

1.3 The new domain theory should say something about: Distribution networks, Substations, Breakers, Protective relays, Customers, Loads, Lines, Transformers, Disconnectors, Fuses, Bus-bars, Shunts, Generators, Taps, Connecting nodes, Customer agreements.

1.4 Modelling type: Static modelling.

1.5 Degree of concretisation: We want to model the distribution network such that the ontology becomes useful for the application but also such that the ontology can be used by other applic ations in the future.

Step 2: Make a preliminary design and base it on an existing ontology

In this step we need to get an idea of how we should model the knowledge objects identified in step 1.3. We should select ontologies from the ontology base, which represent the knowledge objects. As already stated, the ontologies from (Bernaras et al 1995) for the transmission networks should be useful. In particular, the Structural ontology includes most of the knowledge objects from step 1.3. Some objects are missing but are very similar to some of the concepts from the Structural ontology, e.g. fuses which are very similar to breakers.

Two objects are a little different from the others. Customers and Customers agreements are not represented in the Structural ontology, which is perfectly in order, since they have no structural role in the network. The customers are included in loads in the electrical network, see Figure 1. The Customers and Customers agreements have to be modelled separately. This is done in the section*Customer ontology for distribution networks,* below. All of the knowledge objects identified in step 1.3 except the two customer related objects will be modelled in a *Structural ontology for distribution networks*. It will be based on the Structural ontology from (Bernaras et al 1995), which includes an IS-A hierarchy, a CONSIST-OF hierarchy and some other relations to model the flow of energy. The latter relations describe the topology for the transmission network suitable for the applications which were described in (Bernaras et al 1995). For the optimal distribution system configuration application, we need a little different topology. Therefore, we have separated the topology from the Structural ontology for distribution networks and model the topology separately in the section *Topological ontology for distribution networks*, below. The base for that will be the generic topological ontology documented in (Benjamin & Jansweijer 1995).

Step 3: Make a definitive design and assess the design

We have in the previous steps identified the knowledge objects we want to model and found the ontologies we want to use as a base for our modelling. In the following subsections we build the new ontologies, (Actually we build a Domain theory which hopefully may act as ontology in the future. For formal descriptions of Domain theories and Ontologies, see [Oster95]). All editing and mappings has been performed with the help of the KACTUS toolkit, Void version 2.5. Parts of the CML code (Schreiber et al 1994) generated by the KACTUS Toolkit is included in the paper. The CML code also includes more details, such as certain properties, than what is documented in the following subsections.

Step 4: Document and allow the design to be reused

The documentation of the design should be done during the previous steps. This text is a part of the documentation. The design will be made accessible to other knowledge engineers by saving the ontologies in the KACTUS Ontology Library.

Structural ontology for distribution networks

The Structural ontology for transmission networks from (Bernaras et al 1995), showed to be a very good description of the distribution networks. Most of the knowledge objects are present and are well described.

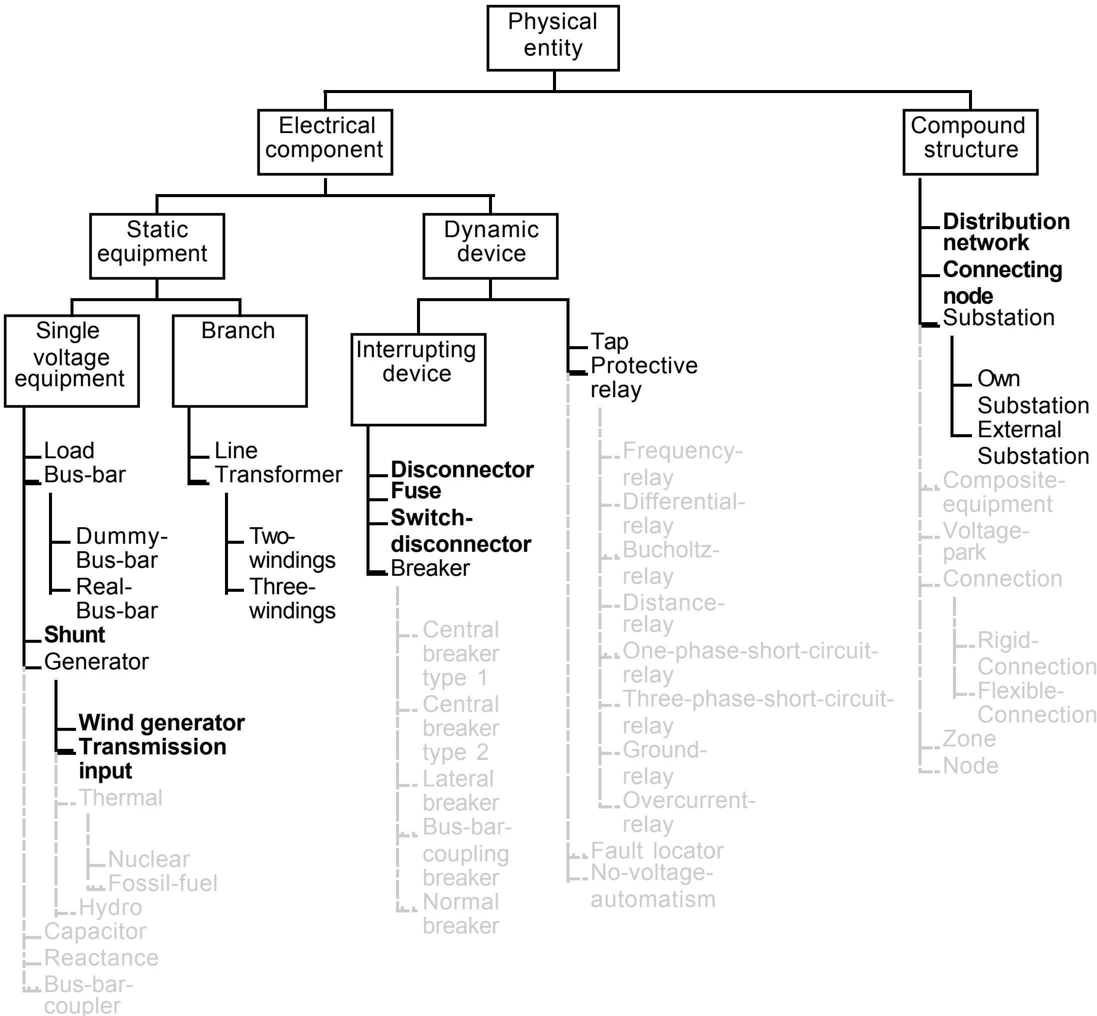

Figure 1: IS-A hierarchy of the Structural ontology for distribution networks. The concepts in bold face are new concepts for distribution networks and the grey ones are concepts that were excluded from the Structural ontology for transmission networks.

All objects are considered as Physical entities and split up into Electrical components and Compound structures. The Electrical components are then split up depending on if they are static or dynamic, single-voltage-equipment or branches etc. All these distinctions seem to be relevant for distribution networks as well. In Figure 1, the modified Structural ontology for distribution networks are represented. New concepts are marked with bold face and concepts which for some reason were not needed are still in the figure but in grey.

The main changes from the Structural ontology from (Bernaras et al 1995):

• All the Single voltage equipment are present in the distribution networks but we chose to exclude Bus-bar-couplers which did not seem relevant for the application.

• Capacitors and Reactances are most relevant when minimizing losses in the network but they have principally the same function, so we have replaced them with the concept Shunt.

```
CONCEPT shunt;
    DESCRIPTION: "It is an impedance, whose objective
        is to regulate the power by means of its capacity
        to generate or consume reactive-power.";
    SUB-TYPE-OF: single-voltage-equipment;
    PROPERTIES:
        max-reactive-power: INTEGER;
        min-reactive-power: INTEGER;
        reactive-power-consumption: INTEGER;
        current-reactive-power: REAL;
```

```
    previous-reactive-power: REAL;
    reference-reactive-power: REAL;
    objective-reactive-power: REAL;
END CONCEPT shunt;
```

• Loads and Generators work as sinks and sources in the network. Generators are not as common in distribution networks as in transmission networks and especially Nuclear, Fossil-fuel and Hydro generators are usually not present in a distribution network. In the distribution networks of Sydkraft there are some Wind power stations which are introduced as Wind generators in Figure 1. The main source of power to the distribution network is, of course, the connections with the transmission network. It is introduced as Transmission input.

```
CONCEPT wind-generator;
  DESCRIPTION: "It is a generator that produces
      lectrical energy by transforming wind energy.";
  SUB-TYPE-OF: generator;
END CONCEPT wind-generator;

CONCEPT transmission-input;
DESCRIPTION: "It is a point where the Distribution
      network and the Transmission network are
      connected to each other. From the distribution
      network point of view, this point is a source of
      electrical power, which means that it has the role
      of a generator. ";
  SUB-TYPE-OF: generator;
END CONCEPT transmission-input;
```

• Fuses are added to the Interrupting devices. Fuses are not used in transmission networks.

```
CONCEPT fuse;
  DESCRIPTION: "Interrupting device, which opens
      when the energy flow through it exceeds a
      predefined limit or when there is a short-circuit
      current. It has to be replaced after use.";
  SUB-TYPE-OF: interrupting-device;
END CONCEPT fuse;
```

• Disconnector was called Switch in the Structural ontology from (Bernaras et al 1995), but Sydkraft did not recognise that term, they wanted to call it Disconnector.

```
CONCEPT disconnector;
  DESCRIPTION: "It is an interrupting-device that
      cannot open when energy
      flows through it. It only accepts manual-
      operations.";
  SUB-TYPE-OF: interrupting-device;
   PROPERTIES:
      telemetering: BOOLEAN;
END CONCEPT disconnector;
```

• Switch-disconnector is a new component, which is something between Disconnector and Breaker. Its main difference from Breaker is that it cannot break short-circuit currents.

```
CONCEPT switch-disconnector;
   DESCRIPTION: "Interrupting device, which can open
      when energy flows through it. It can be triggered
      by control devices and by manual operations. It
      cannot break short-circuit currents.";
  SUB-TYPE-OF: interrupting-device;
END CONCEPT switch-disconnector;
```

• The different kinds of breakers are not relevant for this application.

• Taps are important for minimization of losses and Protective relays need to be adjusted after a change in the network. All the different kinds of Protective relays do not, however, seem necessary to model for our purposes.

• Fault locators and No-voltage-automatisms are uncommon in distribution networks and they are of no importance for our application.

• The role of the compound structures is to group the components. This can be done in many ways and it turned out that we only need Substation, Distribution network and Connecting nodes for our application. Substation is included in the Structural ontology from (Bernaras et al 1995) and Distribution network corresponds to Static network. Connecting node is a new concept which is important in the topology, which will be further explained in the section *Topological ontology for distribution networks*, below.

The Compound structures consist of components or other Compound structures. In Figure 2, the CONSIST-OF relations are structured in a hierarchy. On the highest level, the Distribution network is a collection of Lines and Connecting nodes. The Connecting nodes could consist of Dummy-Bus-bar, Loads (Customers), Disconnectors or whole Substations. Substations can consist of many different kinds of components.

In the Structural ontology from (Bernaras et al 1995), there is a consists-of relation between Transformer and Tap, but Transformer is not modelled as a compound structure. Our view is that the compound structures are concepts which have as their most important property that they consist of other concepts.

Transformer is different from the other compound structures, since it is an electrical component in itself. It is true, though, that the Taps are inside transformers but the important thing is that a transformer is controlled by taps.

Therefore, we have introduced the new binary relation CONTROLLED-BY-TAP.

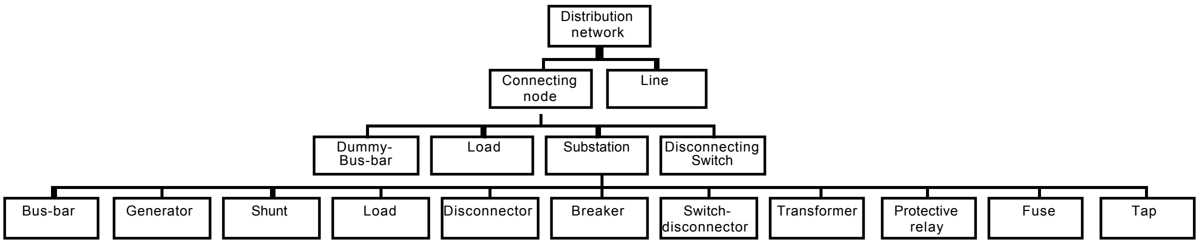

Figure 2: CONSIST-OF hierarchy of the Structural ontology for distribution networks

Topological ontology for distribution networks

A very important piece of knowledge of an electrical network is how the components are connected to each other. According to (Wielinga et al 1996), the topology can be modelled on different levels. For the minimization of losses application, we are most interested in what, in the (Wielinga et al 1996), is called Level 1, i.e. how lines connect Connecting nodes from a geographical point of view. In (Benjamin & Jansweijer 1995), the Connecting nodes are just Substations, but in our case it can also be Dummy-bus-bars, Loads or Disconnectors, see Figure 3.

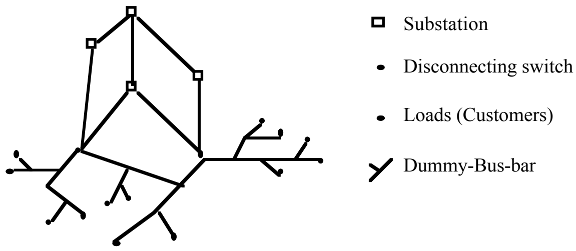

Figure 3: Example of a distribution network

This kind of topology is not present in the Structural ontology from (Bernaras et al 1995), but the generic topological ontology from (Benjamin & Jansweijer 1995), defines a topology that we can use. This topology consists of Graphs, Nodes, Edges and Ports. Graph corresponds in our case to Distribution network, Nodes corresponds to Connecting Nodes and Edges corresponds to Lines. The only thing we do not have is Port. A Port is the interface of a Node to which the Edge can be connected. It is not always obvious which components in the electrical network that acts as Ports but that is in fact not so important. The important thing is that to each node there are a correct number of ports associated to it. Therefore, we introduce the concept Port which has a topological function but is not important otherwise. The relations in the Topological ontology are shown in Figure 4. The most important relation is the Connects relation, which specifies that two Ports are connected via a Line. There is no need for the Unconnected relation in this topology.

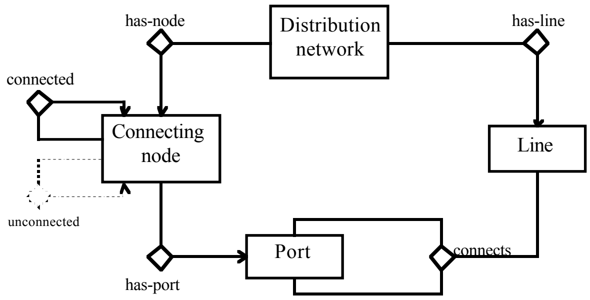

Figure 4: Topological ontology for Distribution networks (To be completed)

Customer ontology for distribution networks

The role of customers are much more important in distribution networks than in transmission networks. In transmission networks the “customers“ are large industries or distribution networks. These consume a very large amount of power and by “the Law of Large Numbers“ the variation of consumption is small. That is not the case for the customers in distribution networks, which are smaller industries and private customers. The variation of consumption is very large. Industries probably consume power mostly in the daytime and private customers consume most power during the evening, perhaps in order to cook dinner.

When minimizing the losses in the network, the large variations in consumption is a big problem. The mathematical optimization needs specified input of how much power each customer is going to consume in the nearest future. The means we have at hand today to estimate the future consumption of the customers is a categorization of the customers. The customers belong to different categories if they, for example, are farmers or not, or if they use the electrical power to heat their house or not etc. All these categories, today about 70, have different consumption behaviours, which are statistically well documented. So, we need the concept Customer which has a property Customer-category.

As the electrical power market is deregulated, the freedom of the customers to choose power distributing companies increases. One effect of this is that different power companies try to give the customers special offers, which tend to get more and more complex. A power salesman can for example offer the customer reduced rates if the customer has power failure more than a certain amount of hours per year. These kinds of agreements affects, of course, the optimal distribution system configuration since we might consider it more important to have a very secure connection to such a customer instead of the connection which have the smallest losses.

Unfortunately, we did not find any ontology in the ontology base which models the concepts Customer or Customer agreement. Therefore, we constructed a new, very small, ontology which is shown in Figure 5.

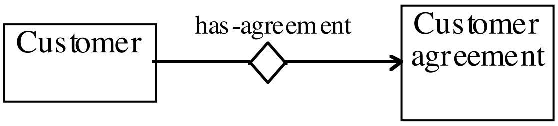

Figure 5: Customer ontology

Some kind of relation or mapping is needed which connects Customers and the Loads in the network. Generally, each customer corresponds to one load in the electrical network, but often one load can be the sum of a few customers.

Conclusions and future directions

This is, as far as we know, the first time an external company outside the KACTUS consortium has been involved in a research experiment within KACTUS. Sydkraft has not participated in the ontology building but they have given all the necessary input for that process. We used the Structural ontology (Describing an Electrical Transmission network) from (Bernaras et al 1995) as input for the discussions and it turned out that it was a very good base to work from. It was both a support for us knowledge engineers and for the domain experts. There were of course some questions about terminology and why some concepts were modelled in certain ways, but the overall structure was very good. The ontologies constructed here are, consequently, heavily influenced by the ontologies from (Bernaras et al 1995) and if the application we had in mind get realized, we can really verify if the ontologies are useful.

We have tried to use the Ontology modelling sequence from (Ostermayer et al 1995) and it helped to structure the work. Two of the design principles in (Ostermayer et al 1995) are modularization and standardization. As an modularization effort we split the design into three different ontologies. For the topology we used the standard proposed by the generic topological ontology from (Benjamin & Jansweijer 1995). In the context of standardization, it is worth pointing out that there are a lot of concepts which now have been used both by the Spanish power company Iberdrola and the Swedish power company Sydkraft, which means that we could be close to obtain a standard Structural ontology for electrical networks.

We used the KACTUS Toolkit to graphically edit the ontologies representing the transmission network to create the distribution network ontologies and finally automatically generated CML code. This process of reuse of ontologies has made the work much easier and saved us a lot of time. The ontologies we used as bases for the modelling were taken from the KACTUS Ontology Library.

Acknowledgements

We would like to thank Hans Gjöderum and Daniel Karlsson at Sydkraft, who have been very helpful with information about their electrical distribution networks and also Amaia Bernaras, Inaki Laresgoiti at Labein and Jose Corera at Iberdrola for their assistance explaining the Electrical Transmission Network Ontologies, and finally we would like to thank Annika Widmark at Cap Gemini (former Cap Programator) for assisting and informing us of how to use the KACTUS toolkit and for all great fun during the KACTUS project.

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