Chapter 4
Power Distribution Asset Categorization

The main objective of the research is to develop the decision support tool to assist an asset manager in making a decision on the distribution feeder rehabilitation investment. Based on the asset management framework of balancing risks, costs, performances as well as compromising the benefits of all stakeholders, the proposed tool has to be equipped with all necessary information and knowledge required for organizing, evaluating, and making decision. The asset categorization is thus developed to support such action. To obtain the required information and knowledge, the knowledge workers, i.e. utility staff, are needed to be interacted using knowledge engineering techniques to capture and codify what information and knowledge they use while they are performing the intended tasks.

Power system distribution network comprises of many electrical and structural components that formed up into the system to serve the main function of distributing electrical power from main substation to customer at two voltage level, either medium voltage or low voltage. Medium voltage feeder, the main focus of this research, which conveys electrical power from substation medium voltage bus to distribution transformer also consist of several components. For example, if it is an overhead type it may consist of poles, insulators, wires, and switches; while an underground type consists of cables, joints, terminations, and, sometimes, a sort of duct to encase these cables. During the operation, the distribution network facilities may encounter a number of stresses and hostile environment that can deteriorate the network components and even fail the network performance. The asset categorization proposed in this thesis is aimed to classify distribution network assets into categories that featured with attributes indicating potential risk of network failure. In addition, the asset manager might want to know how much it costs him if such risk is to be improved or prevented; a cost component of an asset shall also inhere in a proposed categorization to turn into a cost idea if he takes such preventive action. Finally, to assist the manager brings about the ultimate decision whether a certain distribution network reinforcement project should be implemented or not, the proposed categorized asset should also feature with relevant information required for the final decision making. The development of asset categorization is essentially required the methodologies of knowledge engineering discussed in previous chapter.

4.1 Chapter Overview

The process of categorization, from the beginning till the end, employs numerous steps and techniques. This chapter is dedicated to exemplify methods in use. The chapter starts with the objectives of asset categorization, and followed by the terminological description of terms related to categorization. Then the ontology development approach is briefly touched. The languages used for information modeling are subsequently discussed. Finally, the proposed categories of power distribution network assets are focused in the last section.

4.2 Objective of Asset Categorization

In the simplest term, categorization is the way that people divide objects existing in the world into the groups whereas each group has to share common feature. The categorization not only helps people manage things they encounter easily but also allows them to learn new things by just comparing the features of the new object with existing ones. The ability to group things according to a common characteristic and then name that characteristic is a basic concept that helps children form a basis for structuring and organizing their world [57]. Categorization strategies can become a system for learning, problem solving and organizing. It is also a foundation for processing, remembering and integrating new information.

The objective of asset categorization offered in this thesis is to facilitate the management of power distribution network asset, particularly the distribution feeder. The developed categorization strategies would help the asset manager to organize, evaluate, and making decision on feeder rehabilitation investment. Although there are works done by various international bodies such as The International Electrotechnical Commission (IEC), The Institute of Electrical and Electronics Engineers (IEEE) or The Electric Power Research Institute (EPRI) to offer the standardized terminologies for communicating among utilities, vendors and consultant but there does not exist the asset category that provides information needed for feeder rehabilitation investment decision making. Those categorization frameworks are mainly employed for power system control functions [58, 59, 60, 61]. The main reason behind the asset categorization proposed in the thesis is two folds:

- To facilitate an assessment on feeder performance, i.e. risk, cost, or social and environment impact.
- To provide knowledge on how the distribution feeder can be formed up

Hence, the developed taxonomical structure of asset categories as well as asset category itself should provide information required for the performance assessment and design of the feeder.

For the design of the feeder, the asset categorization illustrates all the components as well as its functionalities that required forming up the feeder. In terms of risk assessment, the asset category would equip with the asset features, functionalities, stressors and environments of operation. For cost assessment, the asset category has to provide the types and cost idea of individual component used to form up the feeder. In addition, the impact of risk to stakeholders shall also be given. Finally, in the social and environment view point the asset category has to present the idea on what impact the feeder would pose to people’s livings such as safety, city landscape, accidents, etc.

4.3 Categorization Terminology

Categorization may have different definition depend upon the context of its usage. Merriam-Webster’s online dictionary [62] defines a categorization as “the basic cognitive process of arranging into classes or categories”. Wikipedia [63], a free online encyclopedia, elaborates it more as a process in which ideas and objects are recognized, differentiated and understood. Categorization implies that objects are grouped into categories, usually for some specific purpose. Ideally, a category illuminates a relationship between the subjects and objects of knowledge. Categorization is fundamental in language, prediction, inference, decision making and in all kinds of environmental interaction. Another definition that given by [64] has two folds: the first has to do with the function of category systems and asserts that the task of category systems is to provide maximum information with the least cognitive effort. The second principle has to do with the structure of the information so provided and asserts that the perceived world comes as structured information rather than as arbitrary or unpredictable attributes. Categorization as applied in categorizing power distribution system assets in the context of asset management should involve particularly in grouping the distribution feeder component into certain group based on its functionality, failure risk implication, and cost induction.

In order to generate the required asset categorization, the concepts behind categorizing process shall be clarified and made understood. It is thus that the description of terminological glossary used in this thesis shall be firstly introduced. These terms include controlled vocabulary, classification, taxonomy, ontology and metadata.

4.3.1 Controlled Vocabulary

The most effective communication occurs when all parties involved agree on the meaning of the terms being used. When people converse, they speak in natural language which by nature is raw, rich, varied and sometimes confused amongst the speakers. To prevent such confusion, especially when speaker are not in the position to be allowed for further clarification of the context in talk, people thus need to impose some order to facilitate agreement between the concepts within the talk and the vocabulary of the person using it [65]. This order can come through a controlled vocabulary. Controlled vocabulary is as way of describing a concept under a single word or phrase. In different domain the controlled vocabulary may vary in its definition and usage. In the library science for example, a controlled vocabulary [66] is an established list of standardized terms used for both indexing and retrieval of information. An example of a controlled vocabulary is subject headings used to describe library resources. A controlled vocabulary ensures that a subject will be described using the same preferred term each time it is indexed, making it easier to find all information about a specific topic during the search process.

Controlled vocabulary makes a database easier to search, makes searching more efficient and precise and essentially it can also assist in cataloging resources. In order to make a controlled vocabulary having an unambiguous, non-redundant definition, the list of terms should be controlled by and be available from a controlled vocabulary registration authority [67]. This is a design goal that may not be true in practice. It depends on how strict the controlled vocabulary registration authority is regarding registration of terms into a controlled vocabulary. At a minimum, the following two rules should be enforced:

- If the same term is commonly used to mean different concepts in different contexts, then its name is explicitly qualified to resolve this ambiguity.

- If multiple terms are used to mean the same thing, one of the terms is identified as the preferred term in the controlled vocabulary and the other terms are listed as synonyms or aliases.

In power distribution arena, the terms used in communication among people and software agents are somehow controlled by the standards designed for referencing. For example, the international standard IEC 60287 defines the vocabularies used in the subject of XLPE insulated power cables. The problem may also arise if different party tries to talk to each other but uses different reference standards; or a company may have their own jargons rooted in their life-long experiences. The later section shows how this problem can be alleviated. Nevertheless, the controlled vocabularies are basically essential for efficient and effective communication.

4.3.2 Classification

Merriam-Webster online dictionary has given the definition of classification as systematic arrangement in groups or categories according to established criteria. Oxford Advanced Learning's dictionary [68] puts the similar definition as the act or process of putting people or things into a group or class. The well-known book of knowledge engineering and management methodology, CommonKADS, [38] uses a classification approach as one of the methodologies to extract and organize knowledge from data captured into a certain group. The CommonKADS cites that the classification is concerned with establishing the correct class (or category) for an object where an object needs to be characterized in terms of class to which it belongs. The underlying knowledge typically provides for each class constrains on the values of object features.

From definitions given by diverse sources as shown above, it can be concluded that the classification is an approach to systematically arranging objects into categories according to established criteria. Objects are either the physical or the conceptual things that exist in the universe. Hardware, software, documents, animals, human beings, and even concepts are all examples of objects. Basically, the controlled vocabularies are used to refer to an object of interest. Classification has offered several benefits to people's lives. It helps them to learn a new thing, by evaluating the thing they come across against what they have already known; ease people to understand and memorize things. Classification also allows to human being to manage things easily by grouping them into certain category under specific criteria and then manipulate against established condition, e.g. a certain value which such criteria might contains.

Electric power system assets can also be classified into a group of a certain feature in order to facilitate the management of such asset. For example, these assets might be classified into generation, transmission, and distribution according to the nature of network and its business. Furthermore, the distribution network assets can also be organized into either medium voltage and low voltage or overhead and underground. Such classification makes electric power delivery assets much easier to manage.

4.3.3 Taxonomy

Merriam-Webster online dictionary is again referred to of which defines taxonomy as an orderly classification of plants and animals according to their presumed natural relationships. A clear example of taxonomy is the animal kingdom taxonomy. For example, Kingdom “animals”, class “mammals”, order “primates”, genus “homo”, species “homo sapiens”, which is an human. This is a taxonomy based on the presumed “is a kind of” relation. Taxonomy can thus best be described as a hierarchy created according to data internal to the items in that hierarchy [69, 70]. Another literature [67] views taxonomy as a collection of controlled vocabulary terms organized into a hierarchical structure. Each term in taxonomy is in one or more parent-child relationships to other terms in the taxonomy. In essence, taxonomy is an orderly classification of objects into hierarchical structure using a parent-child relationships. There may be different types of parent-child relationships in taxonomy, e.g., whole – part, genus – species, type – instance, or class – subclass.

Taxonomy may differ from classification in the sense that taxonomy classifies in a structure according to some relation between the entities and that a classification uses more arbitrary (or external) grounds [69]. As an example of internal grounds, a dog is an animal but not every animal is a dog, so dog is a subclass of animal. The decision to place a dog in the category animal is based upon data inherent to the entities, so this would be a piece of taxonomy, i.e. taxonomy with a subclass hierarchy.

The common information model (CIM) packages [61] could be the best example to demonstrate taxonomy of power system assets. CIM models power system components into classes with their associated attributes. It uses ‘is-a ’and ‘part-of’ taxonomy of concepts to organize these assets into hierarchical structure. The main object of CIM was originally designed to facilitate an information interchange to gain an efficient and fair power trade among power utilities using energy management system (EMS) [71]. More details of CIM concept will be elaborated in the later section of the chapter.

4.3.4 Ontology

Merriam-Webster online dictionary explains the word ontology as a branch of metaphysics concerned with the nature and relations of being. In artificial intelligence (AI) community, an ontology is viewed as an explicit specification of a conceptualization [72]. From knowledge-based systems point of view, it is defined as a system of concepts used as building blocks of an information processing system [73]. Further explanation is given in [74] that an ontology consists of concepts, hierarchical (is-a) organization of them, relations among them, in addition to is-a and part-of, axioms to formalize the definitions and relations.

If taking a closer look into the definition given in [72] which is widely accepted in ontological engineering community, there are two significant terms: the specification and conceptualization which is challenging to exemplify explicitly. The exact meaning of ontology depends on the understanding of the terms specification and conceptualization. Explicit specification of conceptualization means that an ontology is a description (like a formal specification of a program) of the concepts and relationships that can exist for an agent or a community of agents [75]. This definition is consistent with the usage of ontology as set of concept definitions, but more general. A conceptualization is an abstract, simplified view of the world that is intended to represent for some purpose. And the ontologies are designed for the purpose of enabling knowledge sharing and reuse. In this context, an ontology is a specification used for making ontological commitments which is an agreement to use a vocabulary (i.e., ask queries and make assertions) in a way that is consistent (but not complete) with respect to the theory specified by an ontology. Conceptualization is language independent, while ontology is language dependent [76]. The specification guides people to acquire knowledge about the domain whereas the conceptualization helps them organize and structure this knowledge using external representations that are independent of the implementation language and environment [77].

Although taxonomy and ontology are interchangeably used in many literatures they are fundamentally having the differences in their meanings. While taxonomy classifies objects in a domain in hierarchical structure, ontology offers more by expressing meaningful content within a specified domain of interest. A taxonomy is just a classification of things in hierarchical manner. They do two things: give exact names for everything in a specified domain and show which things are parts of other things. An ontology, on the other hand, is like a taxonomy in that it is going to contain all the entities in the domain, and show the relationships they have to each other. However, it does more; it has strict, formal rules (a "grammar") about those relationships that let people make meaningful, precise statements about their entities/relationships. A formal ontology is hence a controlled vocabulary expressed in an ontology representation language [67]. This language has a grammar for using vocabulary terms to express something meaningful within a specified domain of interest. The grammar contains formal constraints, e.g., specifies what it means to be a well-formed statement, assertion, query, etc. on how terms in the ontology's controlled vocabulary can be used together.

4.3.5 Meta-model

Metadata, simply put, is a "data about data" [63]. It is used to facilitate the understanding, characteristics, and management usage of data. The description of field in relational database like MS Access or SQL is a kind of metadata. A meta-model is an explicit model of the constructs and rules needed to build specific models within a domain of interest. A valid meta-model is an ontology, but not all ontologies are modeled explicitly as meta-models [67]. In essence metadata is a schema which is used to specify or restrict the structure of the documents. XML schema and RDF schema are examples of metadata.

In conclusion, in order to develop the categorization of objects for a certain application it shall be relied greatly on ontology development. The process of categorization can be summarized as follows:

- the (controlled) vocabularies involved with the objects in consideration have to be agreed among the concerned parties;
- the criteria for categorizing such objects into certain classes (classifications) have to be established;

- the taxonomical relationships between classes have to be defined and laid out, e.g. 'is-a 'and 'part-of' relationships;
- the formal rules (a "grammar") about those relationships that let people make meaningful, precise statements about the entities (classes) and relationships have to be established by some form of ontology representation language;
- finally, a certain schema (metadata) which will be referenced for formalizing the proposed categorization shall be drawn.

The following sections depicts in more details on how those terminologies can be turned into distribution asset categorization.

4.4 Information Modeling Language

As stated previously, the distribution system asset categorization is proposed based on ontology development which requires a form of representation language. This section is hence devoted to illustrate the modeling language that will be employed for such asset categorization. However, the term of information modeling language is used instead of ontology modeling language for the sake of generality.

This section starts with the description of unified modeling language (UML), then carries on to extensible markup language (XML), resource description framework (RDF) before concluding with common information model (CIM) which is regarded as the foundation framework for the proposed asset categorization.

4.4.1 Unified Modeling Language (UML)

The UML is a visual, object-oriented, and multi-purpose modeling language [78]. While primarily designed for modeling software systems, it can also be used for other modeling applications such as business process modeling or knowledge modeling. UML is an industry standard and proprietary and language independent so that it may be used in any number of development environments. Most of UML elements are graphical: lines, rectangles, ovals and other shapes, and many of these graphical elements are labeled with words that provide additional information.

UML consists of various diagram types which provide a uniform framework needed for all software systems modeling. These include use case diagram, class diagram, object diagram, sequence diagram, collaboration diagram, state diagram, activity diagram [79]. In this thesis however, only UML class diagram will be discussed since the information modeling involve mainly with this type of UML diagram. This is based on the fact that UML class diagrams can provide a useful means of visually representing object hierarchies. More explanation of UML class diagram and its associations [79, 80, 82, 82, 83] are provided as the followings.

Classes

Each class can have its own internal attributes and relationships with other classes. Each class can be instantiated into any number of separate instances, known as objects, each containing the same number and type of attributes and relationships, but with their own internal values.

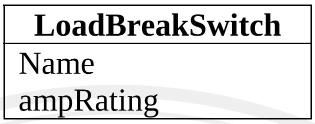

Figure 4.1 The LoadBreakSwitch class

A simple example of a class can be depicted as shown in figure 4.1. The LoadBreakSwitch class contains two basic attributes: Name and ampRating. If the system being created were to represent every LoadBreakSwitch in the distribution network, it would require only this single class since every load break switch within the distribution network can be represented at the most basic level by the attributes defined in LoadBreakSwitch. That is if the distribution network contains the 100 load break switches, the system would create 100 separate instances of the LoadBreakSwitch class, each containing a value for Name and amprating independent of the other 99 instances (although not necessarily unique).

Generalization

A generalization is a relationship between a more general and a more specific class. The more specific class can contain only additional information. For example, a Feeder is a specific type of Equipment Container. Generalization provides for the specific class to inherit attributes and relationships from all the more general classes above it.

The following figure is an example of generalization. It can be clearly seen that a LoadBreakSwitch is a more specific type of Switch, which in turn is a more specific type of ConductingEquipment, which is itself a more specific type of PowerSystemResource. A PowerTransformer is another more specific type of PowerSystemResource.

Figure 4.2 provides a class hierarchy to represent some of the different types of Power System Resource (PSR) that exist within a distribution network. This diagram, as with all subsequent class diagrams uses standard UML symbol. Conducting Equipment and Power Transformer are both sub-classes of PSR. A Conducting Equipment is still a PSR and still has a Name and Description, but has additional attributes to identify the phase it belongs. Similarly, a Power Transformer is still a PSR, but has gained new attributes to indicate Type and Cooling Type. Switch is sub-class of Conducting Equipment which automatically inherits all the attributes of its parent, at the same time adding the Normal Open, Switch On Count and Switch On Date into its attributes. The bottommost of this class hierarchy is Load Break Switch which is a kind of Switch but has a new attribute of Ampere Rating.

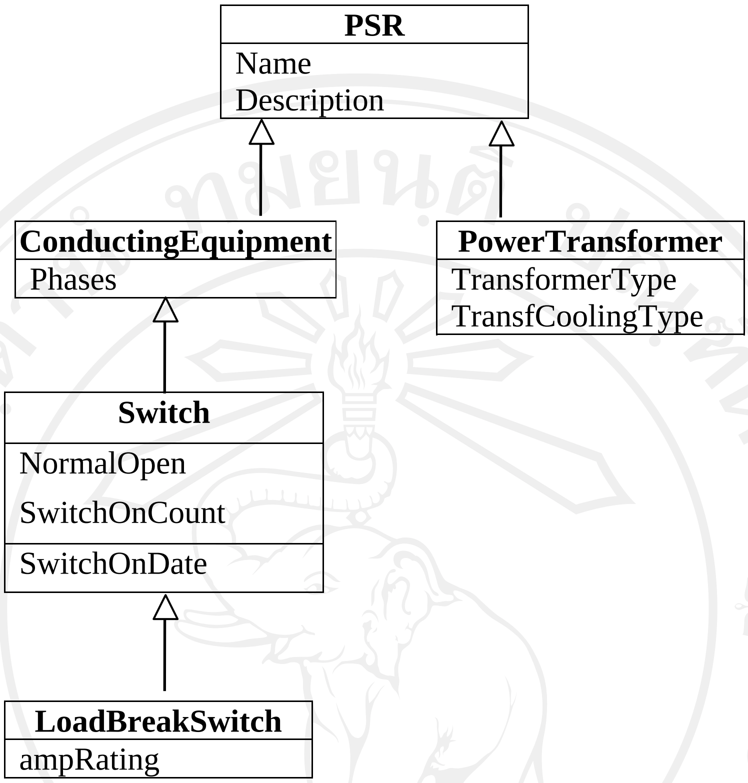

Figure 4.2 Example of Generalization

Association

An association is a conceptual connection between classes. Each association has two roles. Each role is a direction on the association that describes the role the target class (i.e., the class the role goes to) has in relation to the source class (i.e., the class the role goes from). Roles are given the name of the target class with or without a verb phrase. Each role also has multiplicity/cardinality, which is an indication of how many objects may participate in the given relationship. For example, as shown in figure 4.3 there is an association between a Feeder and Cost which can be read as Feeder generates Cost. At each end of the association link is the multiplicity. In this example, a Feeder object may contain 1 Cost while a Cost can be a member of 0 or 1 Feeder.

Figure 4.3 Example of Association

Aggregation

Aggregation is a special case of association. Aggregation indicates that the relationship between the classes is some sort of whole-part relationship, where the whole class "consists of" or "contains" the part class, and the part class is "part of" the whole class. The part class does not inherit from the whole class as in generalization.

Figure 4.4 Example of Aggregation

Unlike a simple Association relationship the line denoting a relationship on the diagram contains a diamond instead of an arrowhead. This indicates that the two classes have an Aggregation relationship. This can be thought of as “a Feeder contains 1 or many Conductors whereas a Conductor is a member of only one Feeder”, indicating that the relationship is stronger than a simple association”. The clear diamond, however, indicates that the two are not completely inter-dependent, and that if the Feeder was destroyed the Conductor would still exist (assuming the destruction was not a literal demolition but instead indicated that the Feeder had ceased to exist).

Composition

Composition is a specialized form of Aggregation where the “contained” object is a fundamental part of the “container” object, and that if the “container” is destroyed; all the objects that are related to it with a composition are simultaneously destroyed.

Figure 4.5 Example of Composition

An example of this is shown in figure 4.5 between the Splice class and the Conductor class. The line here has a solid diamond, indicating that the relationship is a composition. The multiplicity states that a conductor will have 0 or more splices and that a splice will be contained within 1 conductor only. If a conductor is destroyed then the splices within it are also destroyed.

4.4.2 eXtensible Markup Language (XML)

XML stands for eXtensible Mark-up Language endorsed by World Wide Web Consortium (W3C) as a standard for data format. It is a markup language much like HTML but designed to describe the data by tags. However, XML tags are not predefined; users have to define their own [84]. XML is a simple and flexible text format. It is very popular for structured, semi-structured and unstructured data exchange over Internet and private networks [85]. It is platform independent but able to transform to other database application without difficulty. XML allows users to define information structures that reflect their business needs, often by defining open industry-wide standards that facilitate data exchange, CIM/XML for example. XML simplifies exchange of information among businesses or applications dramatically by using the same formatting technique regardless of the structure of the underlying data. The same information can easily be formatted, extracted, compiled, summarized, etc. many times in many different ways for many different purposes [86].

To model the data with XML, syntax of data needs to be defined among the users. The syntax of XML is simple and consists of a properly nested set of open and close tags, where each tag can have a number of attribute-value pairs. Every element is enclosed in tags. Figure 4.6 below shows a very simple example of XML document describing the distribution feeder object. Here you can see that data which is encoded in a plain text are put between predefined and usually self-descriptive tags. For example, a <ampacity unit = “amp” >400</ampacity> clearly denotes the current carrying capacity of feeder in ampere.

```
<Feeder ID = “KT411” >
        <ratedVoltage unit = “volt”>24,000</ratedVoltage>
        <ampacity unit = “amp”>400</ampacity>
        <UndergroundCable>
                <conductorSize unit = “sqmm” >400</conductorSize >
                <length>350</length>
        </UndergroundCable>
        <OverheadCable>
                <conductorSize unit = “sqmm” >185</conductorSize >
                <length>1,250</length>
        </OverheadCable>
</Feeder>
```

Figure 4.6 XML document describing distribution feeder

XML syntax rules require that all tags be properly nested with only one root element existing in one XML document. It is essential to create an exact definition of syntax: elements and attributes and the occurrence frequencies of the elements within a document. This can be done in XML using Document Type Definitions (DTD) or XML Schema Document (XSD) [84]. XSD is an XML based alternative to DTD, which has a different way of defining elements. Although, both of them specify the syntax of the XML document but XML schema, beside its complexity, offers more flexibility to structure XML document than DTD. An XML schema defines element and attribute names for a class of XML documents. The schema also specifies the structure that those documents must adhere to and the type of content that each element can hold. However, it can be concluded that if an XML document conforms to the accompanying DTD or XSD file it is said to be valid.

Figure 4.7 explains how XML schema provides a definition of syntax for XML document given in figure 4.6.

```xml
<?xml version="1.0" encoding="UTF-8" ?>
 <xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
 <xs:element name="ampacity">
        <xs:complexType mixed="true">
            <xs:attribute name="unit" type="xs:NMTOKEN" use="required" />
        </xs:complexType>
 </xs:element>
 <xs:element name="conductorSize">
        <xs:complexType mixed="true">
            <xs:attribute name="unit" type="xs:NMTOKEN" use="required" />
        </xs:complexType>
 </xs:element>
 <xs:element name="Feeder">
        <xs:complexType>
        <xs:sequence>
            <xs:element ref="ratedVoltage" />
            <xs:element ref="ampacity" />
            <xs:element ref="UndergroundCable" />
            <xs:element ref="OverheadCable" />
        </xs:sequence>
        <xs:attribute name="ID" type="xs:NMTOKEN" use="required" />
        </xs:complexType>
 </xs:element>
 <xs:element name="length">
        <xs:complexType mixed="true" />
 </xs:element>
 <xs:element name="OverheadCable">
        <xs:complexType>
        <xs:sequence>
            <xs:element ref="conductorSize" />
            <xs:element ref="length" />
        </xs:sequence>
        </xs:complexType>
</xs:element>
<xs:element name="ratedVoltage">
        <xs:complexType mixed="true">
            <xs:attribute name="unit" type="xs:NMTOKEN" use="required" />
        </xs:complexType>
 </xs:element>
 <xs:element name="UndergroundCable">
        <xs:complexType>
        <xs:sequence>
            <xs:element ref="conductorSize" />
            <xs:element ref="length" />
        </xs:sequence>
        </xs:complexType>
 </xs:element>
 </xs:schema>
```

Figure 4.7 Annotated simple XML Schema example describing the data within a feeder

4.4.3 Resource Description Framework (RDF)

Although XML provides a standardized format to facilitate an information interchange among the applications, it needs concerning parties to agree on a common schema of their XML documents; otherwise the problems with an interoperability may occur. However, as already known, huge amount knowledge of interests are published and distributed throughout the Internet; in order to gain a full potential use of such knowledge, the Semantic Web has been introduced. An XML cannot offer a format for semantic interoperability; it is just formalism for defining a grammar, so anything can be encoded in XML if a grammar can be defined for it. But it needs two things for the Semantic Web. It needs common formats for integration and combination of data drawn from diverse sources. It is also about language for recording how the data relates to real world objects. That allows a person, or a machine, to start off in one database, and then move through an unending set of databases which are connected not by wires but by being about the same thing [87]. To this end, the Resource Descriptive Framework (RDF) comes into plays [88].

RDF is a method for expressing knowledge in a decentralized world and is the foundation of the Semantic Web, in which computer applications make use of distributed, structured information spread throughout the Web [89]. An RDF defines a nested object-attribute-value structure. When it comes to Semantic Interoperability, RDF has significant advantages over XML; i.e. semantic units are given naturally through is object-attribute structure, all objects are independent entities. A domain model, defining objects and relationships of a domain of interest, can be represented naturally in RDF, so translation steps, as required when using XML, are not necessary [91]. The RDF data model is drawn from Knowledge Representation. It is a simple and general view of information and therefore relatively easy to project onto other models. Once that is done, RDF syntax can be used to encode the information and RDF schema can be used to describe or constrain it [91].

RDF is underpinned by a triple of the form: Subject – Predicate – Object, also known as *statement*. It is like an English sentence. Subjects, predicates, and objects are names for entities also called *resources* (from web) or *nodes* (from graph terminology), whether concrete or abstract, in the real world. Names are either global and refer to the same entity in any RDF document in which they appear, or local, and the entity it refers to cannot be directly referred to outside of the RDF document. Objects can also be text values, called literal values. An alternative form of RDF statement is RDF is an object – attribute - value triple [92]. Either form also refers to the same principle. Figure 4.8 shows an RDF statement graphically. In triple form, figure 4.8 can be said as “Feeder has Ampacity of 400 A”.

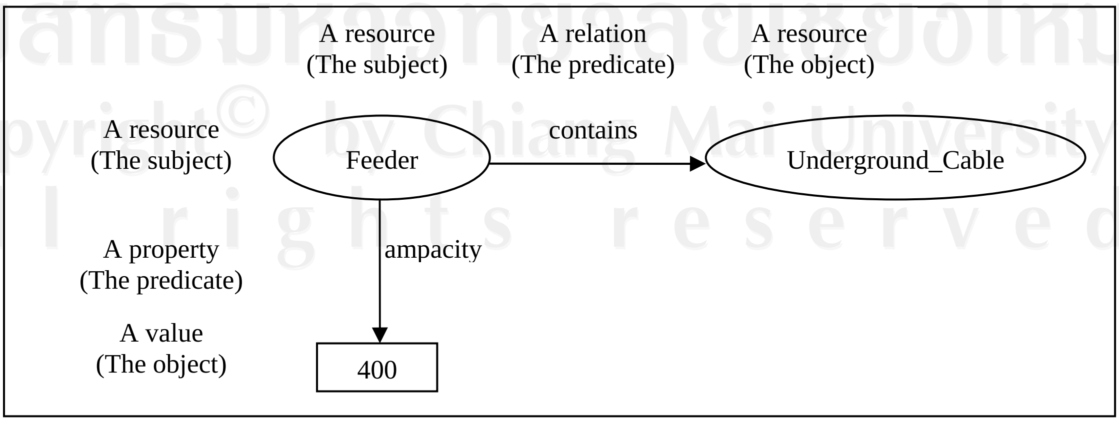

Figure 4.8 RDF statement as a graph

Similarly as XML schema providing the syntax rules for XML document; RDF schema specifies information about classes in a schema, including properties (attributes) and relationships between classes. On the other hand, format and relation in RDF document are given in RDF schema. RDF schema provides a typing system, informally it is a basic set of nodes and relations that can be used to express properties of classes of the schema. RDF schema includes a facility to indicate that certain classes are subclasses of others, and provides a small number of basic classes. Finally, it contains a facility for specifying a small number of constraints such as the cardinality (number of occurrences) required and permitted of properties of instances of classes.

RDF's conceptual model is a graph (as depicted in figure 4.8). RDF provides an XML syntax for writing down and exchanging RDF graphs, called RDF/XML. Unlike triples, which are intended as a shorthand notation, RDF/XML is the normative syntax for writing RDF. RDF/XML is defined in the RDF/XML syntax specification. Figure 4.9 below illustrates the RDF/XML version of figure 4.8 graph.

```
<?xml version='1.0'?>
<!DOCTYPE rdf:RDF [
        <!ENTITY rdf 'http://www.w3.org/1999/02/22-rdf-syntax-ns#'>
        <!ENTITY aim 'http://camt.info/aim#'>
        <!ENTITY rdfs 'http://www.w3.org/2000/01/rdf-schema#'>
]>

<rdf:RDF xmlns:rdf="&rdf;"
        xmlns:aim="&aim;"
        xmlns:rdfs="&rdfs;">

<aim:UndergroundCable rdf:about="&aim;feeder_rdf_Instance_1"
        aim:conductorSize="400.0"
        aim:length="350.0"
        aim:name="Feeder_1_UG_1"
        rdfs:label="feeder_rdf_Instance_1"/>

<aim:Feeder rdf:about="&aim;feeder_rdf_Instance_1"
        aim:ampacity="400.0"
        aim:commissioningDate="20000301"
        aim:name="Feeder_1"
        rdfs:label="Feeder_1">
        <aim:containCable rdf:resource="&aim;feeder_rdf_Instance_1"/>
</aim:Feeder>

</rdf:RDF>
```

Figure 4.9 RDF document of statement shown in figure 4.8

```
<?xml version='1.0'?>
<!DOCTYPE rdf:RDF [
        <!ENTITY rdf 'http://www.w3.org/1999/02/22-rdf-syntax-ns#'>
        <!ENTITY aim 'http://camt.info/aim#'>
        <!ENTITY a 'http://protege.stanford.edu/system#'>
        <!ENTITY rdfs 'http://www.w3.org/2000/01/rdf-schema#'>]>
<rdf:RDF xmlns:rdf="&rdf;"
        xmlns:aim="&aim;"
        xmlns:a="&a;"
        xmlns:rdfs="&rdfs;">
<rdfs:Class rdf:about="&aim;Feeder"
        rdfs:label="Feeder">
        <rdfs:subClassOf rdf:resource="&aim;aim"/>
</rdfs:Class>
<rdfs:Class rdf:about="&aim;UndergroundCable"
        rdfs:label="UndergroundCable">
        <rdfs:subClassOf rdf:resource="&aim;aim"/>
</rdfs:Class>
<rdfs:Class rdf:about="&aim;aim"
        rdfs:label="aim">
        <rdfs:subClassOf rdf:resource="&rdfs;Resource"/>
</rdfs:Class>
<rdf:Property rdf:about="&aim;ampacity"
        a:maxCardinality="1"
        a:range="float"
        rdfs:label="ampacity">
        <rdfs:domain rdf:resource="&aim;Feeder"/>
        <rdfs:range rdf:resource="&rdfs;Literal"/>
</rdf:Property>
<rdf:Property rdf:about="&aim;commissioningDate"
        a:maxCardinality="1"
        rdfs:label="commissioningDate">
        <rdfs:domain rdf:resource="&aim;Feeder"/>
        <rdfs:range rdf:resource="&rdfs;Literal"/>
</rdf:Property>
<rdf:Property rdf:about="&aim;conductorSize"
        a:maxCardinality="1"
        a:range="float"
        rdfs:label="conductorSize">
        <rdfs:domain rdf:resource="&aim;UndergroundCable"/>
        <rdfs:range rdf:resource="&rdfs;Literal"/>
</rdf:Property>
<rdf:Property rdf:about="&aim;containCable"
        rdfs:label="containCable">
        <rdfs:domain rdf:resource="&aim;Feeder"/>
        <rdfs:range rdf:resource="&aim;UndergroundCable"/>
</rdf:Property>
<rdf:Property rdf:about="&aim;length"
        a:maxCardinality="1"
        a:range="float"
        rdfs:label="length">
        <rdfs:domain rdf:resource="&aim;UndergroundCable"/>
        <rdfs:range rdf:resource="&rdfs;Literal"/>
</rdf:Property>
<rdf:Property rdf:about="&aim;name"
        a:maxCardinality="1"
        rdfs:label="name">
        <rdfs:domain rdf:resource="&aim;aim"/>
        <rdfs:range rdf:resource="&rdfs;Literal"/>
</rdf:Property>
</rdf:RDF>
```

Figure 4.10 RDF schema of figure 4.8 example

4.4.4 Common Information Model (CIM)

The CIM is a model with coverage for the domain of electric generation, transmission and distribution [58]. CIM defines a utility industry standard object model for the development and integration of applications used for electric power systems engineering, planning, management, operation and commerce [59]. The CIM is comprised of a specification and a schema. The specification defines the details for integration with other management models. It includes expressions for common elements that must be clearly presented to management applications such as; object classes, properties, methods and associations. The specification defines syntax, rules, meta schema, meta schema elements, and the rules for each element. The schema provides the actual model descriptions. It supplies a set of classes with properties and associations that provide a well-understood conceptual framework within which it is possible to organize the available information about the managed environment.

The CIM [60, 61] provides a comprehensive, logical view of EMS information for transmission network analysis, generation control, SCADA, and operator training simulation. The CIM is documented as a set of class diagrams using the UML. UML specifies the CIM in an abstract manner that allows for open implementations (i.e., there is no restriction to relational or object oriented or other modeling technologies). Figure 4.11 shows a fragment of the CIM class diagram in UML notation. As shown in Figure 4.8, the base class of the CIM is the PowerSystemResource class, which is defined to represent a generic power system component. Derived from this abstract class are a variety of subclasses representing various power system equipment entities, such as lines, capacitors, breakers, transformers, and substations. Relationships between classes are also represented including resource ownership, groupings into substations, etc. The CIM systemically names each class, its attributes and relationships, thus creating a common data dictionary that facilitates system and application integration in the EMS industry.

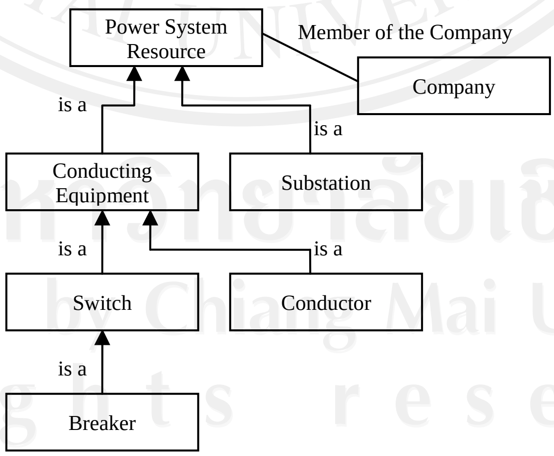

Figure 4.11 A fragment of the CIM Wires model

Since CIM has been originally developed for the EMS application, it is used as an information model for information interchange among utilities when they share system information for the purpose of power system control. Although it later extended to distribution management system (DMS) [93] and provided framework for asset management application but it is still new to the real application.

The CIM XML language is an application of RDF to CIM. It is defined by a confluence of the CIM, RDF schema, and RDF syntax specifications.

Although the CIM itself modeled as an UML diagram provides useful insight to the important objects within the power industry, it is difficult to exchange data due to the fact that object related databases are available but not widely in use. Instantiated objects must be represented via serialization formats which can exchange data in binary or text format. The IEC proposed an RDF schema as a proper way to exchange data in a common format [61]. The CIM RDF schema is documented as the IEC standard 61970-501 [94]. Like any other XML-based format, it has several advantages over binary formats. Due to XML based mechanisms, it is possible to extend the CIM with versioning mechanisms and, more important, with namespaces as a mechanism which is easily extensible and supports site-specific needs. CIM RDF is both machine and human readable and self-describing although it is primarily intended for programmatic access by tools which support the Document Object Model (DOM) API. Current web standards can be met when using a RDF based representation of the data providing more semantics than plain XML.

Figure 4.12 and 4.13 below describes an example of a description of a breaker class using RDF Schema and RDF document.

```
<rdf:Description rdf:about="http://iec.ch/TC57/2001/CIM#Breaker">
        <rdfs:subClassOf rdf:resource="http://iec.ch/TC57/2001/CIM#Switch"/>
        <rdfs:isDefinedBy rdf:resource="http://iec.ch/TC57/2001/CIM#Package_Wires"/>
        <rdfs:label xml:lang="en">Breaker</rdfs:label>
        <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class"/>
</rdf:Description>

<rdf:Description rdf:about="http://iec.ch/TC57/2001/CIM#Breaker.ampRating">
        <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#DatatypeProperty"/>
        <rdfs:range rdf:resource="http://iec.ch/TC57/2001/CIM-schema-
        cim10#CurrentFlow"/>
        <rdfs:isDefinedBy rdf:resource="http://iec.ch/TC57/2001/CIM#Package_Wires"/>
        <rdfs:label xml:lang="en">ampRating</rdfs:label>
        <rdfs:comment>Fault interrupting rating in amperes</rdfs:comment>
        <rdf:type rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#Property"/>
        <rdfs:domain rdf:resource="http://iec.ch/TC57/2001/CIM#Breaker"/>
</rdf:Description>
```

Figure 4.12 A Sample of CIM RDF schema definition [58]

```
<cim:Breaker rdf:ID=”_7">
        <cim:Breaker.normalOpen>false</cim:Breaker.normalOpen>
        <cim:Naming.name>LBS</cim:Naming.name>
        <cim:SubstationComponent.MemberOf_VoltageLevel rdf:resource="#_5"/>
        <cim:ConductingEquipment.Terminals rdf:resource="#_31"/>
        <cim:ConductingEquipment.Terminals rdf:resource="#_32"/>
</cim:Breaker>
```

Figure 4.13 A Sample of CIM RDF document [58]

4.4.5 Protégé-2000: Knowledge Modeling Tool

Protégé-2000 [56] is an integrated software tool used by system developers and domain experts to develop knowledge-based systems. Applications developed with Protégé-2000 are used in problem-solving and decision-making in a particular domain.

Protégé is a frame-based environment for knowledge based system development. An ontology in Protégé consists of classes, slots, facets and axioms [95]:

- *Class* frames specify domain concepts and are organized in a subsumption hierarchy that allows for multiple inheritances. Classes are templates for individual instance frames.
- *Slots* are special frames that can be attached to classes to define their attributes, with specific value type restrictions. Own slots define intrinsic properties of class or individual instance frames that do not get propagated either by inheritance or instantiation. Template slots are attached to class frames to define attributes of their instances, which in turn define specific values for slots. Slots in Protégé are first-class objects. They can be specified both globally for the ontology and locally as attached to classes, where their properties are overridden. Each slot is an instance of a meta-slot class that defines its properties.
- *Facets* are properties of slots, which specify constraints on their allowed values. Examples are the cardinality of a slot value, its type (primitive, such as string or integer, or complex, such as instance of a class), range and default values, etc.
- *Axioms* are additional constraints that can be defined on frames, for example to link the values of a group of template slots attached to a class.

Protégé also enables developers to create persistence layer components to import knowledge bases from (and then export to) external storage formats such as a DBMS. This possibility can be combined to the use of the meta-class architecture to redefine a specific knowledge model for a given representation format. This way, Protégé was recently adapted to support the creation and editing of RDF schema ontologies and the acquisition of RDF instance data.

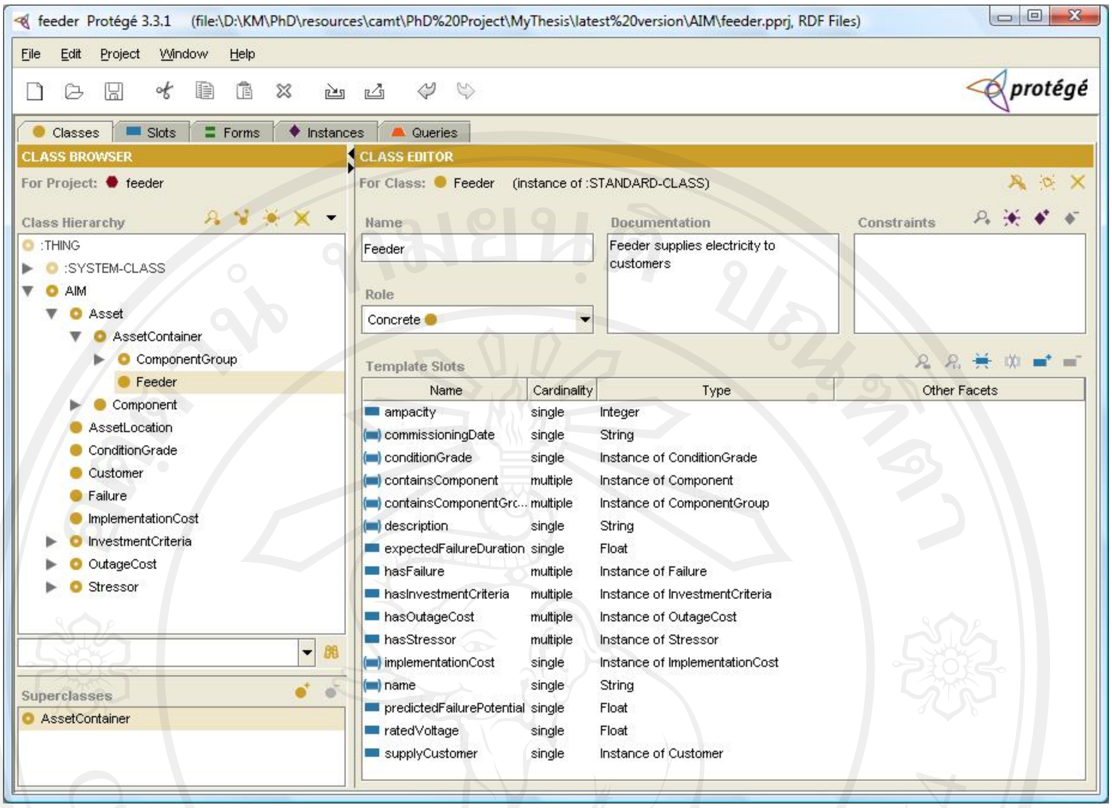

Figure 4.14 The representation of ontology in Protégé-2000.

The Protégé tool accesses all of these parts through a uniform GUI (graphical user interface) whose top-level consists of overlapping tabs for compact presentation of the parts and for convenient co-editing between them. This "tabbed" top-level design permits an integration of (1) the modeling of ontology of classes describing a particular subject, (2) the creation of a knowledge-acquisition tool for collecting knowledge, (3) the entering of specific instances of data and creation of a knowledge base, and (4) the execution of applications. Figure 4.14 and 4.15 show the screen shots of Protégé – 2000 working with.

The left-hand panel of figure 4.14 contains the class hierarchy. The selected class Feeder is a subclass of AssetContainer which in turn a subclass of Asset and AIM respectively. The right-hand panel is the form for the class Feeder containing the own slots for the class and their values and the template slots attached to the class along with their value restrictions - facets.

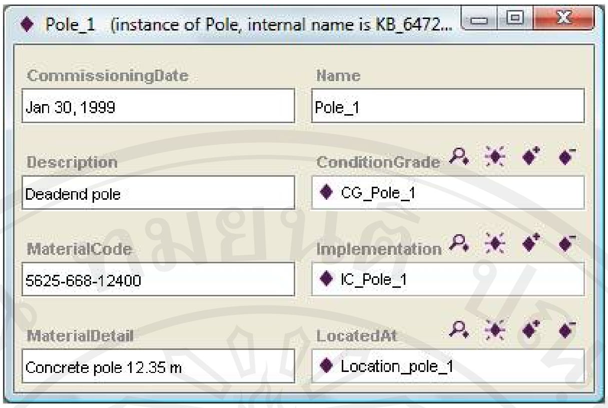

Figure 4.15 An instance of a class Pole.

Figure 4.15 shows the value of each slot that contained in class Pole. All the slots on the form are own slots.

4.5 Categorization of Power Distribution Network Asset

The decision support framework introduced in chapter 2 has outlined the process for making decision on how to invest for distribution feeder rehabilitation. It starts from determining the possibility of feeder failure, quantifying of associated costs and finally evaluating these attributes with other governing criteria to bring about the final decision; that is what investment option utility shall adopt to rehabilitate their distribution feeders. In order to do so, the information on existing network components has to be identified and made available to an inference engine of the system. On the other hand, in order to effectively performing an assessment of distribution network failures, costs associated with such failure as well as costs incurred if such failure is to be mitigated, the knowledge on how the distribution network is to perform under the specific operational condition and external environment has to be discerned and categorized into groups of relevant, i.e. asset categories. These asset categories might relate to network concrete components such as poles, conductors, ducts, or cables, and abstract things such as locations, measurement, or conditions. Essentially, the asset categories would provide all necessary information and knowledge required for making a decision.

In this section, the process of distribution network asset modeling is discussed; modeling approach and language are described; and finally, the asset categories which will be used in the proposed decision support system are tabulated.

4.5.1 Requirements for Asset Decision Making

The extreme goal of decision support system is to provide a decision maker with a clear view on which option is the most favorable to invest in reinforcing a power distribution network. The goal is set in accordance with the principle of investment decision framework as described in chapter 2. That is, “asset management strategy is employed to systematically optimize costs, risks, and performance along the asset life cycle through the effective investment decision."

There are thus four key elements involved in the decision making process; that is: business profit, customer service, network performance, and social welfare. Utility business is a kind of social infrastructure. On the other hand, the electric energy is regarded as the fundamental needs of our present society. Every power utility has to operate its business in conformity with a regulatory framework. High profit is not thus an option for its business; cost is a major concern of each utility. Claiming for profit is valid only if all costs incurred in network investment being sensible.

In the view point of distribution network performance the elements of customer service and network performance share the same context, i.e. the risk of network failure. The service level mentioned here is level of power supply reliability and quality that utility offering to its customer. As such, the failure of power distribution network directly impacts the service level and poses risk to utility business. Failure could also generate some costs to the concerned parties. If the distribution network fails to supply the energy; utility loses revenue; residential customers' living are disturbed by power blackout; and commercial and industrial customers lose an opportunity to produce the goods for sales.

The last element seems to be kept out of a nowadays asset management equation. Instead, social and environmental concern is now gaining more and more an attention from present society. This might be an aesthetic issue that a distribution line would harm landscape scenery. Safety of the people and their properties living nearby is another issue. Difficulty of day-to-day living that caused by the presence of network facilities are also now a topic of discussion.

All of these elements need to be made clear and notified to an investment decision maker in order that the most favorable investment option shall be achieved. In essence, the core value of asset management of cost and risk minimization and performance maximization are thus realized effectively.

In addition to the main requirements as illustrated above, this research also considers another aspect that is required to make the decision support system comprehensive, flexible and robust. That is where the asset categorization comes into focus. The proposed asset categorization offers all necessary requirements and characteristics needed for system comprehensiveness, flexibility and robustness. Issues that considered here include:

- Network asset knowledge representation;
- Provision of information of individual asset and interaction among them via key attributes and relationships;
- Possibility of system extension or integration with other systems;
- Use of existing ontology;
- Ability to manipulate using available software application;

4.5.2 Asset Modeling Process

The asset categorization proposed here is based on the concept of CIM which in turn relies itself on RDF knowledge representation methodology. To give a clear picture on how the introduced asset categorization for power distribution network asset management is developed, the modeling steps employed to attain the require categories of network assets are discussed in this section.

Steps involving in modeling power distribution system asset to formulate an asset categorization in this thesis include:

- Defining purpose, domain and scope
- Probing questions and informal descriptions of domain knowledge
- Analyzing knowledge description to capture concepts and properties
- Considering the reuse of existing ontology
- Modeling asset classes and relationships
- Verifying the model interchangeability, expressivity, reusability, extensibility and integratability

Defining purpose, domain and scope

Purpose: To determine risks, costs and socials factors associated with the implementation of power distribution network.
Domain: Encompass medium voltage distribution feeder including network components, network operation, and operational environment
Scope: Limited to information that aids determining risks, costs and socials factors involved with distribution feeder.

Probing questions and informal description of distribution feeder

The knowledge elicitation techniques of interview and protocol analysis are used to interact with utility experts. This is done through posting the questions to the experts and collects the answers. In response to the question, experts might give straight answer to the question, elaborate the relevant context, or provide information descriptions to the inquirers depending on the level of their knowledge and articulating ability. However, in order to make the acquisition process continue smoothly the question should be started on the general topics and then narrowing down once the process is going on. In addition to above, experts are sometimes asked to describe verbally while they are performing some inspection and assessment tasks.

The followings are list of probing questions and some key answers in terms of informal descriptions responded by utility experts.

General view:

What is power distribution network?

- It is a part of power system.
- It distributes electric energy from main substation to distribution substations and transformers.
- It situates in diverse landscapes and environments.
- It runs along public road.
- It also runs through field and forest.
- It can be overhead or underground construction or combination of both.

- Overhead power line is placed above ground with appropriate clearance from nearby structures and trees.
- Underground power line is placed under ground with some kind of protection.
- Underground power line can also be put above ground, inside a type of structure, e.g. buildings, bridges, etc.

What are the primary functions of distribution feeder?

- It is used to carry electric current through electrical wire.
- It must able to withstand permanent system voltage or temporary high voltage by means of insulation.
- Operation of distribution feeder must not cause difficulty to living standard or jeopardize the safety of people and environment.
- It may be divided into sections by means of sectionalizer.
- Sectionalizer could be isolator, load-break switch, recloser.
- Sectionalizer provides flexibility for load transfer and fault segregation.

What does an overhead power line look like?

- It is an electrical wire laying or hanging on insulator which in turn supported supporting structure.
- It composes of three main parts, i.e. supporting structure, insulator and wire.
- Supporting structure consists of standing column and x-arm.
- Standing column can be concrete pole, wooden pole, metal column or metal lattice tower.
- X-arm is mounted on standing column and used to support insulator.
- X-arm is made of metal, concrete or wooden.
- Insulator insulates electrical wire from earth potential.
- Insulator can be of pin type, pin-post, suspension, or plastic type.
- Electrical wire is made of aluminum or copper.
- Electrical wire can be of bare or insulated type.
- An insulated wire is primarily intended for avoid temporary earthfault from tree or debris contact.
- Connection of electrical wires can be made through different type of splices.
- etc.

What does an underground power line look like?

- Underground power line consists of cable, joint and termination.
- Cable itself composes of metallic conductor, insulation, electric field control mechanism, and jacket.
- Cable is fully insulated, thus make it able to withstand designed voltage and safe to touch.
- Connection of underground cables is made through special kind of joint.
- Connection between underground cable and other facility is made via cable termination.
- Cable can be directly laid underground, in duct, or in tunnel.
- Cable joint is usually located in joint box or manhole.
- When being laid inside building or manhole, cable must be placed on rack or in tray.

Failure implication:

What is considered to be the failures of distribution feeder?

- When feeder fails to perform an intended function such as carrying electric current, withstanding presence voltage, threatening the living standard.
- When feeder is not capable of supplying demanded load.
- When feeder cannot withstand the designed voltage.
- When feeder lacks of possibility for load transfer and fault segment segregation.

What mechanisms lead to the failures of distribution feeder?

- Feeder is likely to fail when it is over-heated, over-stressed and aging.
- Current flowed in wire produces heat.
- Heat must be dissipated from wire sufficiently.
- Wind helps dissipate heat.
- Surrounding temperature can aid or bar heat dissipation.
- Electrical and thermal stresses also reduce the life of facility.
- Electrical stress is generated by presence voltage.
- Uncontrolled electrical stress leads to the occurrence of partial discharge.
- Partial discharge reduces the life of network component.
- Overload and short-circuit produce thermal stress.
- Mechanical touch on wire conductor leads to short-circuit.
- Polluted environment reduce voltage withstand capability of distribution line.
- Adverse weather condition tends to jeopardize the performance of distribution network.
- Temporary fault is easily occurring on overhead line due to its contact to tree or nearby structures.
- When component is aging, it is losing ability to withstand voltage and may cause a partial discharge activity.

Cost implication:

What are the consequences if distribution feeder fails?

- The electric energy is regarded as the fundamental needs of our present society.
- Power outage costs something to society.
- Power utility does not gain revenue due to unavailability of energy sale.
- Power utility has to expend resources for repair of breakdown components.
- Power utility loses credibility because of power outage.
- Customers lose opportunity to produce and sell their products if power is cut-off.

How much does the failure cost to power utility?

- MEA (Distribution Utility) buys energy from generation company at 2.1137 Baht/kWh and sell to customer at 2.8803 baht/kWh in average.

- Repair of breakdown components needs human workforces, materials, and job management.
- It costs MEA 7,500 baht for 1 hour of repair work.
- Material cost comprises of purchase and inventory costs.
- Company's credibility is always difficult to quantify to monetary value.

How much does it cost to commercial and industrial customers?

- Customers still pay salary or work payment although power is cut-off.
- Power outage may causes loss of some raw materials.
- Re-starting of the process also pose some costs.
- Power outage may cause damage to some equipment.
- Company may need to pay for overtime work in order catch up the production schedule.
- Cost of loss of profit opportunity,
- Utility cannot sell electricity if its distribution network breaks down.

Social factors:

- Nobody wants to see distribution line run nearby their property.
- Construction along public road create mess to people's lives.
- Contact to live wires endangers people's lives.
- Contact of trees to live conductor may fail the feeder.
- Burying distribution network improve city aesthetics.
- Underground cable is safe to touch.
- etc.

Knowledge Analysis to Capture Classes and Attributes

In response to the probing questions, the utility experts provide answers and descriptions relating to the topics in focus as shown in the previous subsection. These descriptions will then be analyzed to form an asset related knowledge representation. The *classification* and *assessment* knowledge template are mainly used in extracting and categorizing the classes and attributes of asset out of those informal descriptions. As well, the RDF triples can be emulated to form a *subject-predicate-object* statement of knowledge representation. For example, experts may explain the distribution feeder as:

- *Pole* is a distribution network *component*
- *Material cost* of *pole* is 8,104.00 baht.
- *Labor cost* of *pole installation* is 8,376.80 baht.
- *Condition grade* of *pole* inspected on *March 20, 2009* is 1.8.
- *Feeder* comprises of *overhead cable* and *underground cable*.
- *Feeder PI417* supplies *Imperial Hotel*.
- etc.

A short grammatical analysis separates these sentences into subjects and objects (shown as nouns in *italic*), the classes and attributes of distribution feeder asset can be attained. But how to decide which noun will be modeled by a class and which noun will be modeled by an attribute follows very simple rule; that is *an attribute can belong to a class, but a class cannot belong to an attribute*. However, it may be the case that a particular class may become an attribute of the other class. For example, in the statement “Feeder PI417 supplies Imperial Hotel” both “Feeder PI417” and “Imperial Hotel” are classes but the “Imperial Hotel” which is a type of class “Customer” is an attribute of class “Feeder”.

Using the methods mentioned above, the main classes of distribution feeder asset with some key of associated attributes are extracted and shown in the table 4.1.

Considering the Reuse of Existing Ontology

Apart from capturing knowledge on distribution network asset from domain experts, other ontologies existed in various sources are also examined. It is always worth considering what someone else has done and checking if such existing sources can be refined and extended for particular domain and task. Reusing existing ontologies may be a requirement if the system needs to interact with other applications that have already committed to particular ontologies or controlled vocabularies. Many ontologies are already available in electronic form and can be imported into an ontology-development environment that being used. The formalism in which an ontology is expressed often does not matter, since many knowledge-representation systems can import and export ontologies. Even if a knowledge-representation system cannot work directly with a particular formalism, the task of translating an ontology from one formalism to another is usually not a difficult one; especially if such ontology is represented in RDF format. In this research study, the CIM ontology [96] is used as a reference in building ontology.

Furthermore, international standard such as The International Electrotechnical Commission (IEC) or The Institute of Electrical and Electronics Engineers (IEEE) also provide common vocabularies as well as functional descriptions of equipment used in the distribution domain. There exists a particular standard governing a certain equipment. For example, IEC60502 would specify the construction, dimensions and test requirements of power cables with extruded insulation and their accessories for rated voltages of 1 kV and 30 kV for fixed installations such as distribution networks or industrial installations. Utility standard such as MEA overhead and underground construction standards provide pictorial descriptions of distribution network construction and installation. These standards provide knowledge on how individual component can be assembled to form the distribution network. All these standards are supplementary resources and very helpful in presented ontology building.

Although this step may be claimed as a separate entity of modeling process, but in practical modeling activities it is incorporated into knowledge analysis process. That is when classes or attributes are found; they would be checked and compared if they have already existed in the relevant standard not. This not only makes such ontologies standardized and agreeable to the people in the area, but also provides the possibility to further research into any other related ontologies. It would thus make ontology development robust and comprehensive.

Table 4.1 The main classes with some of the associated attributes for distribution feeder asset information model

Classes	Main Attributes	Description
Asset	Name Description Commissioning date Condition grade Implementation cost	Distribution network asset in general term
Component	Material code Material detail	Individual distribution network asset
Linear Component	Length	Type of Component that laid along the route
Point Component	Location	Type of Component that mounted at a single coordination
Asset Container	Contain component	Collection of network components that form up particular component group
Feeder	Ampacity Rated voltage Predicted failure potential Expected failure duration Failure Outage cost Customer Stressor Investment criteria	Type of asset container used for supplying electricity to connected load
Location	Coordinate X Coordinate Y	Geographic coordination of asset installation
Condition Grade	Inspection date Grade Relative importance	Rating of physical condition of asset at any time instance
Implementation Cost	Material cost Labour cost	Cost to obtain asset
Failure	Description Date Time duration	Failure event that occur during feeder operation
Customer	ID Type IER Price cap kW Failure Outage cost	Customer being supplied electricity by feeder
Outage Cost	Cost	Cost suffered by customer and utility when feeder fails
Stressor	Degree Description	Operational and environmental stresses that impact feeder operation
Investment Criteria	Degree of importance Description	Criteria that govern the decision on asset investment

Modeling Relationships among Asset Classes

In the former subsection the triple knowledge chunks are analyzed to capture the classes and attributes. Similarly, the relationships between asset classes can also be established. That is the verb of each sentence would represent the relationship between two classes. For example, experts may explain the distribution feeder as:

- Component *is* a kind of asset.
- Asset container *contains* many kinds of components.
- Feeder *is* a kind of asset container.
- Pole *is* a component.
- Conductor *is* a component.
- Insulator *is* a component.
- etc.

The above explanation can then be represented graphically by figure 4.16 whereas the corresponding RDF schema is shown in figure 4.17.

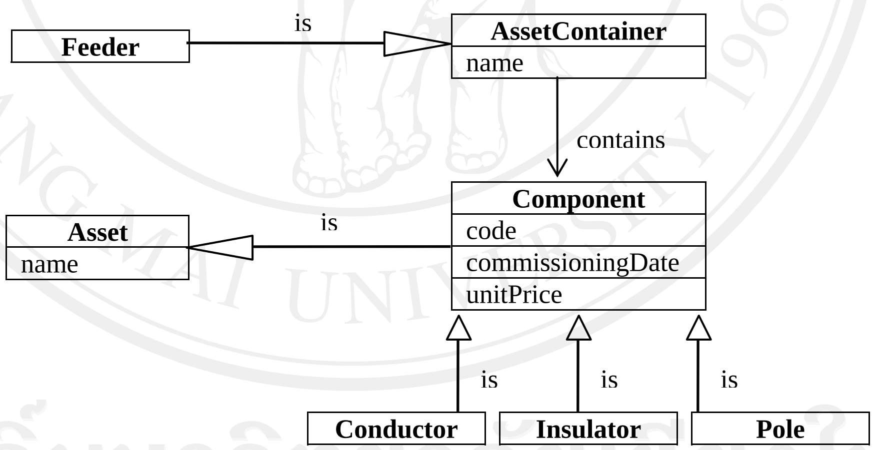

Figure 4.16 Feeder knowledge representations in RDF graph

```
<?xml version='1.0'?>
<!DOCTYPE rdf:RDF [
        <!ENTITY rdf 'http://www.w3.org/1999/02/22-rdf-syntax-ns#'>
        <!ENTITY aim 'http://camt.info/aim#'>
        <!ENTITY a 'http://protégé.stanford.edu/system#'>
        <!ENTITY rdfs 'http://www.w3.org/2000/01/rdf-schema#'> ]>
<rdf:RDF xmlns:rdf=”&rdf;”
        xmlns:aim=”&aim;”
        xmlns:a=”&a;”
        xmlns:rdfs=”&rdfs;”>
<rdfs:Class rdf:about=”&aim;AIM”
        rdfs:label=”AIM”>
        <rdfs:subClassOf rdf:resource=”&rdfs;Resource”/>
</rdfs:Class>
<rdfs:Class rdf:about=”&aim;Asset”
        rdfs:label=”Asset”>
        <rdfs:subClassOf rdf:resource=”&aim;AIM”/>
</rdfs:Class>
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        rdfs:label=”Component”>
        <rdfs:subClassOf rdf:resource=”&aim;Asset”/>
</rdfs:Class>
<rdfs:Class rdf:about=”&aim;ComponentGroup”
        rdfs:label=”ComponentGroup”>
        <rdfs:subClassOf rdf:resource=”&aim;AIM”/>
</rdfs:Class>
<rdfs:Class rdf:about=”&aim;Conductor”
        rdfs:label=”Conductor”>
        <rdfs:subClassOf rdf:resource=”&aim;Component”/>
</rdfs:Class>
<rdfs:Class rdf:about=”&aim;Feeder”
        rdfs:label=”Feeder”>
        <rdfs:subClassOf rdf:resource=”&aim;ComponentGroup”/>
</rdfs:Class>
<rdfs:Class rdf:about=”&aim;Insulator”
        rdfs:label=”Insulator”>
        <rdfs:subClassOf rdf:resource=”&aim;Component”/>
</rdfs:Class>
<rdfs:Class rdf:about=”&aim;Pole”
        rdfs:label=”Pole”>
        <rdfs:subClassOf rdf:resource=”&aim;Component”/>
</rdfs:Class>
<rdf:Property rdf:about=”&aim;code”
        a:maxCardinality=”1”
        rdfs:label=”code”>
        <rdfs:domain rdf:resource=”&aim;Component”/>
        <rdfs:range rdf:resource=”&rdfs;Literal”/>
</rdf:Property>
<rdf:Property rdf:about=”&aim;commissioningDate”
        a:maxCardinality=”1”
        rdfs:label=”commissioningDate”>
        <rdfs:domain rdf:resource=”&aim;Component”/>
        <rdfs:range rdf:resource=”&rdfs;Literal”/>
</rdf:Property>
<rdf:Property rdf:about=”&aim;contain”
        rdfs:label=”contain”>
        <rdfs:range rdf:resource=”&aim;Component”/>
        <rdfs:domain rdf:resource=”&aim;ComponentGroup”/>
        <rdfs:domain rdf:resource=”&aim;Feeder”/>
</rdf:Property>
<rdf:Property rdf:about=”&aim;name”
        a:maxCardinality=”1”
        rdfs:label=”name”>
```

```
            <rdfs:domain rdf:resource=”&aim;AIM”/>
            <rdfs:range rdf:resource=”&rdfs;Literal”/>
</rdf:Property>
<rdf:Property rdf:about=”&aim;unitPrice”
             a:maxCardinality=”1”
             a:range=”float”
             rdfs:label=”unitPrice”>
            <rdfs:domain rdf:resource=”&aim;Component”/>
            <rdfs:range rdf:resource=”&rdfs;Literal”/>
</rdf:Property>
</rdf:RDF>
```

Figure 4.17 The corresponding RDF schema of Feeder knowledge representations

```
<?xml version='1.0' encoding='UTF-8'?>

<!DOCTYPE rdf:RDF [

            <!ENTITY rdf 'http://www.w3.org/1999/02/22-rdf-syntax-ns#'>
            <!ENTITY aim 'http://camt.info/aim#'>
            <!ENTITY rdfs 'http://www.w3.org/2000/01/rdf-schema#'>
]>

<rdf:RDF xmlns:rdf="&rdf;"
            xmlns:aim="&aim;"
            xmlns:rdfs="&rdfs;">

<aim:Feeder rdf:about="&aim;KB_030572_Instance_13"
            aim:name="Feeder_2000"
            rdfs:label="Feeder_2000">
           <aim:contain rdf:resource="&aim;KB_030572_Instance_14"/>
           <aim:contain rdf:resource="&aim;KB_030572_Instance_15"/>
           <aim:contain rdf:resource="&aim;KB_030572_Instance_16"/>
</aim:Feeder>

<aim:Pole rdf:about="&aim;KB_030572_Instance_14"
            aim:code="5625668140"
            aim:commissioningDate="20090131"
            aim:name="Pole_2001"
            aim:unitPrice="3122.81"
            rdfs:label="Pole_2001"/>

<aim:Conductor rdf:about="&aim;KB_030572_Instance_15"
            aim:code="614522920600"
            aim:commissioningDate="20090131"
            aim:name="Conductor_2002"
            aim:unitPrice="181.7"
            rdfs:label="Conductor_2002"/>

<aim:Insulator rdf:about="&aim;KB_030572_Instance_16"
            aim:code="615516057200"
            aim:commissioningDate="20090131"
            aim:name="Insulator_2003"
            aim:unitPrice="859.0"
            rdfs:label="Insulator_2003"/>   </rdf:RDF>
```

Figure 4.18 Sample of Feeder knowledge representations expressed in RDF/XML

Discussion on the model expressivity, interchangeability, extensibility, reusability and integratability

From figure 4.16 above, it can be seen that the model is obviously self described. For example, the actual feeder may be instantiated from the model classes as follow: "Feeder KT-411 contains the concrete Pole no. 2540-001, aluminum bare Conductor and Insulator of pin-post type," which gives the clear picture on how the feeder is assembled. In addition, if one investigates further it he will learn all the information attached to each instantiated object through its attributes. In above example, the Material Code, Unit Price and Commissioning Date could be obtained from the objects. Furthermore, the model is represented using RDF/XML modeling language; it automatically inherits the interchangeable capability of the RDF/XML. So the model would possess the feature of text-based, platform independent, and easily to translate to other format and vice versa.

The X in XML stands for eXtensible. This means that the documents provided from this modeling technique can be extended to model the other needs. The RDF schema can be extended with new classes and attributes by providing a separate namespace. And because a separate namespace is used, the RDF document can clearly define what is the standard model and what is custom. The features described previously can thus make the model extensible, reusable, and integrable.

4.4.3 Proposed Power Distribution Network Asset Model

Integrating the classes and attributes illustrated in table 4.1 and the graphical illustration shown in figure 4.16, the complete power distribution network asset model can be concluded and depicted in figure 4.19 and 4.20. Figure 4.19 shows the relationships of the distribution feeder interacting with the other associated classes. These classes provide all necessary information required for risk and cost assessment as well as knowledge for decision making. For example, it can be said that Feeder *A is* an Asset Container *composing* of Component B and Component *B*, etc. which is used to *supply* electric power to the Customer *D* and *operated* under operational and environmental Stressor E and F, etc.

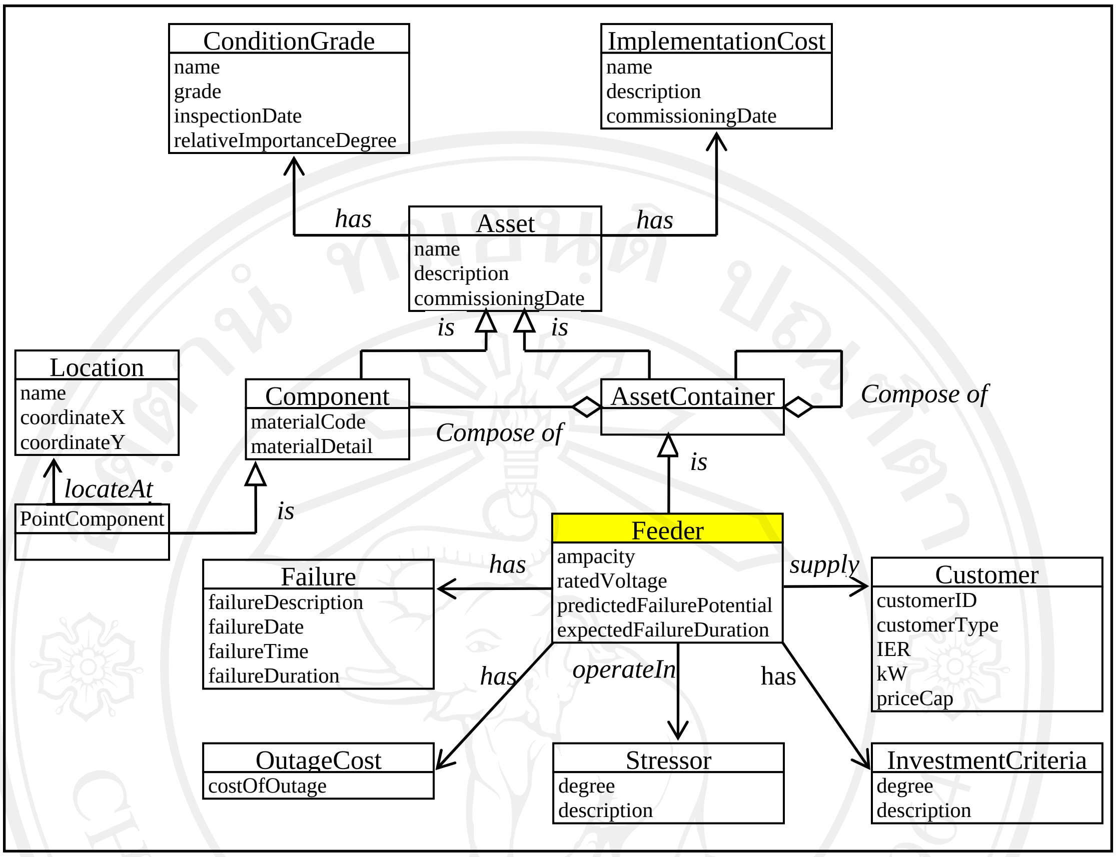

Figure 4.19 Power distribution network asset model

Figure 4.20 depicts the asset model showing the formation of distribution feeder that comprises of many kinds of equipment and groups of equipment. The information resided in the model can be used to design the network as well as risk and cost assessment.

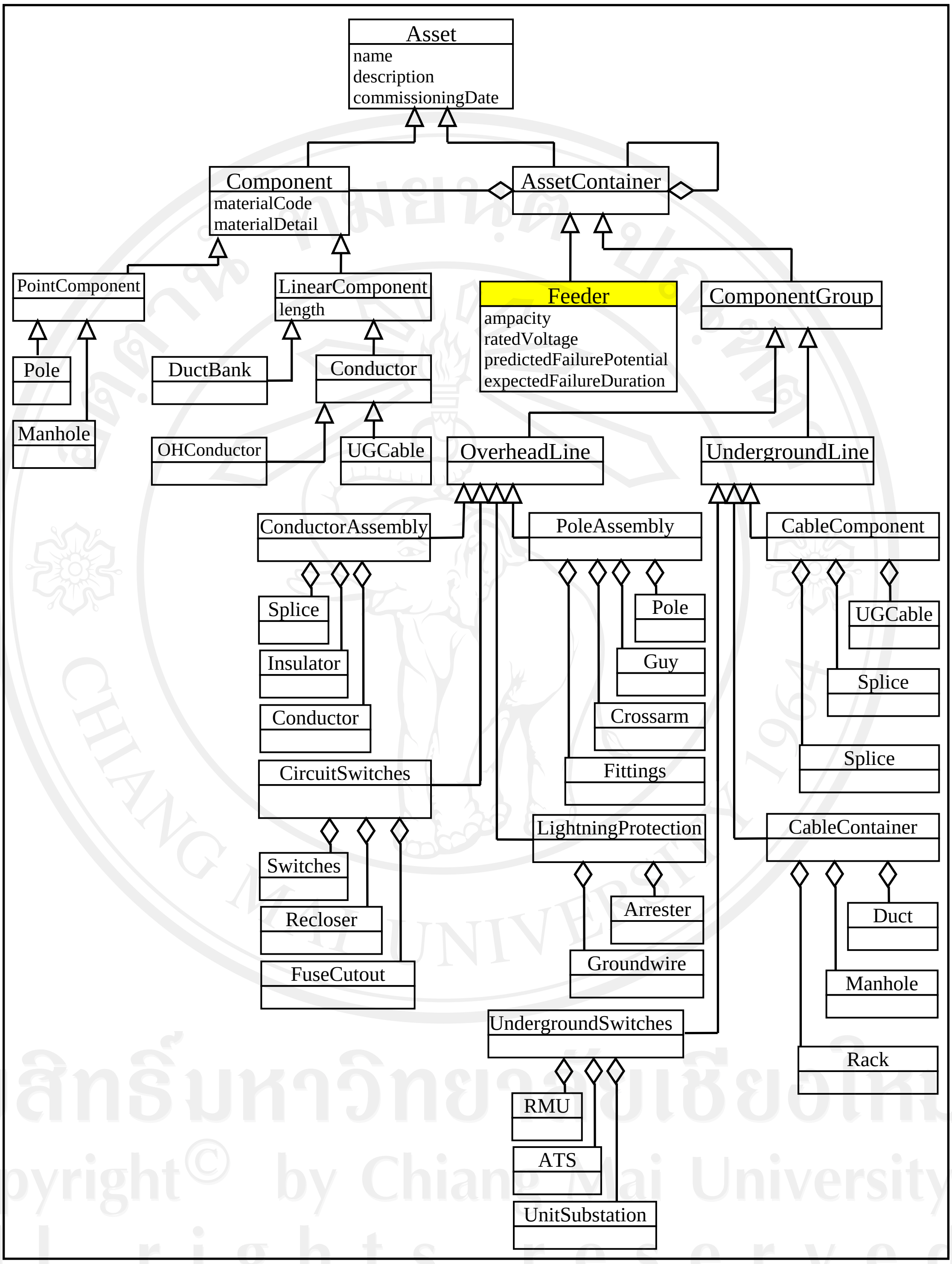

Figure 4.20 Asset model showing the formation of distribution feeder

The application of the proposed asset model in the novel decision support system proposed in this research can be described as follows.

For the risk assessment, the model provide the information of asset condition grade, group of asset it belongs, relative importance degree when compare with other assets, service age of individual asset, degree of operational and environmental stressors in which the feeder is operating.

For the cost evaluation, the model specifies the types and numbers of customer connected to the feeder which in turn provide the kW and IER rating of each customer. The model also gives the implementation cost of each feeder design to the assessor by composing the material and labor cost of all the components that assemble such feeder.

Since the model offers the possibility to outline the feeder design by forming up the feeder configuration, assembling the components (which component is installed in what place and connected to which components), formulating the cost idea and introducing the technical and social matters involved with the feeder implementation, so it will give the knowledge to the assessor to generate the feeder rehabilitation options as well as develop the criteria for decision making.

However, the actual application of asset model will be demonstrated in the following chapters.