CIM Extensions to Electrical Distribution and CIM XML for the IEEE Radial Test Feeders

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***Abstract*—The electric power utility is an extremely large enterprise and has many computer systems and applications to complete both business and engineering functions. An efficient information exchanging and sharing infrastructure is key to the success of an electric utility. To facilitate the integration, a common data model is needed as a common language by which systems and applications can talk with each other. This research focuses on creating a common data model for the electrical distribution. It extends the CIM to electrical distribution for the data requirements by the distribution power flow and proposes modified models for distribution lines, distribution loads, and some specific distribution devices. It converts the IEEE radial test feeders to distribution CIM-based XML documents and provides an initial reference model for the electric distribution data in CIM XML format. These CIM XML documents have been tested and reviewed by industrial contacts. More tests are encouraged to check the interoperability of the proposed model and created CIM XML documents of the IEEE radial test feeders.**

***Index Terms*—Common information model (CIM), distribution management system (DMS), extensible markup language (XML), object-oriented data modeling.**

I. INTRODUCTION

THE electric power utility is an extremely large enterprise. Because of its size and complexity, there are many computer systems designed to complete both business and engineering functions. Often, these systems need to exchange information with each other. Since there is a proprietary data model and storage of each individual system, it is often impossible to integrate the systems together easily. The Electric Power Research Institute (EPRI) proposed an integration framework called control center application program interface (CCAPI), which can be applied both in the control center environment and other areas of the energy enterprise to facilitate the integration of computer systems and applications. The common information model (CIM) is one of the other important parts of this standard. The CIM represents almost all of the major objects in an electric utility enterprise typically contained in an energy management system (EMS) environment. It includes classes, attributes of these classes, and relationships between them. The CIM can be understood as a common language for power system applications to talk to each other. For more details about the EPRI's CCAPI, CIM, and extensible markup language (XML), please see [1]–[3].

The regular operation and control of distribution power systems has become more and more important for utilities under the deregulated and competitive environment. Compared to transmission systems, distribution systems have a much larger amount of data. The distribution system has more applications and systems to support its routine operations and controls. For example, a utility needs a customer information system (CIS) to provide customer information, a geographic information system (GIS) to provide geographic information for the distribution network, and needs an outage management system (OMS) to identify faults and restore the system, to name a few distribution-related systems. In the distribution business arena, there are over 100 software vendors who provide tools for utilities. The electric distribution is an extremely large enterprise and people are looking for more efficient integration solutions for exchanging and sharing information. The previous efforts have been mainly focused on the transmission level. As mentioned before, the CCAPI is an application integration framework specifically designed for the EMS environment and the CIM also represents major objects in an electric utility enterprise typically contained in an EMS environment. In order to support the integration for distribution management systems (DMS), the CIM needs to be extended to distribution networks. Eventually, the CIM should be evolved to a single piece of data model supporting both transmission and distribution applications and systems. The CIM is being standardized through International Electrotechnical Commission (IEC) Technical Committee 57 Working Group 13 (IEC TC57 WG13), and distribution extensions through IEC TC57 WG14. Websites on these efforts are available [4], [5].

This research realized the urgent need for a common distribution model and extended the CIM to distribution networks for the data requirements for distribution power flow applications. The IEEE radial test feeders [6], [7] were used in this work as an initial reference model to provide CIM XML examples of describing distribution network data. The authors anticipate that the proposed CIM models will provide an initial basis to encourage future efforts to modify and extend this model to a comprehensive common distribution model.

II. CHALLENGES FOR THE INTEGRATION WITHIN DMS

The EMS environment is a mature area. The integration of EMS applications using an open architecture environment and

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CIM has been thoroughly discussed and developed. Although there is some level of similarity, the transmission and distribution systems are different in many ways [6].

- Distribution has a very large data model, with size on the order of 500 000 to 10 000 000 objects.
- DMS systems have more external data sources and more application interactions. Typical applications and systems include OMS, CIS, GIS, network management, and network analysis.
- Balanced three-phase modeling is assumed in transmission. Unbalanced three-phase, two-phase, and single-phase must be modeled in distribution analysis.
- Distribution needs details about the feeder model, which is usually modeled simply as a substation load in classical transmission models.

Utilities may have different DMS, but they are facing the same challenges under the deregulated and competitive environment. Distribution operators need the real-time operation information to monitor the system and to support their decisions; dispatchers need crew information and facility information to arrange maintenance and emergency activities; and system planners need historical information for their designs. An individual system may contain information that can be useful across all of the system, and also may need the support of other systems. Compared to EMS, DMS have more data to handle, have more system interactions, have more maintenance and updates, and have to deal with more changes in routine operations and controls. These above issues create an additional challenge for data exchanging, sharing, and system interactions between distribution applications and systems. Due to the size of the system, a more comprehensive common data model for the electric distribution is needed to facilitate the integration. The CIM was originally designed for EMS and, as a consequence, there are drawbacks when using it in electrical distribution.

III. DISTRIBUTION CIM MODELING ISSUES AND TECHNIQUES

Distribution CIM modeling is a huge topic which could include distribution system data, outage data, customer data, geographic data, and asset data. This research work only discusses the modeling issues related to distribution system data (topology, lines, loads, devices, and feeders) for distribution power flow applications. Three major issues, multiphase connection, multiphase attributes, and the whole-part relationship, are discussed in this section. Techniques used to solve these problems are introduced respectively.

A. Multiphase Connection

Electrical distribution is a multiphase network. The distribution CIM model should be able to represent a multiphase connection for the network. Multiphase connections may include multiphase distribution lines, multiphase distribution devices, and multiphase distribution loads. The CIM defines a topology model with the classes of *conducting equipment*, *terminal*, *connectivity node*, and *topological node*. The *conducting equipment* class defines an attribute, phases, to represent the phase type of a conducting equipment like A, B, C, or ABC. The *terminal* class provides 0, 1, or multiple connections for conducting equipment. The *connectivity node* class defines points where terminals of conducting equipment are connected. Basically, conducting equipment has a number of terminals that connect to some connectivity nodes. Connectivity nodes are the points where one terminal connects to other terminals. Fig. 1 illustrates the topology model in the CIM [2].

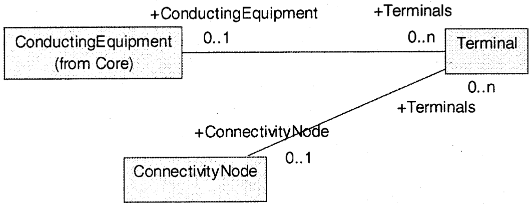

Fig. 1. Topology model defined in the CIM [2].

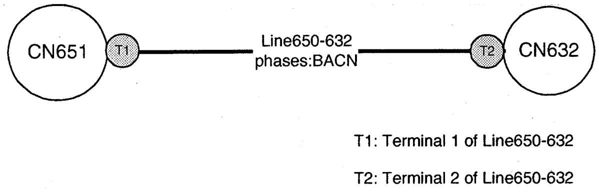

Fig. 2. Connectivity for line 650-632 with terminals and nodes.

Using this model to represent a multiphase network, the first step is to specify phases for conducting equipment. Then, determine how terminals connect to connectivity nodes. For example, the line 650-632 is a three-phase main feeder connected between node 651 and 632 (see the IEEE 13-node feeder in references [6], [7]). An *ac line segment* object is created for this line and the phases attribute is set to BACN. Two terminals are created, which connect to node 651 and 632, respectively. Fig. 2 shows the topology representation for Line 650-632 with terminals and connectivity nodes.

B. Multiphase Attribute

The electrical distribution system is an unbalanced system by nature. A single distribution device may have different attributes for each phase. For example, an unbalanced line has different characteristics for each phase, and an unbalanced load also has different features for each phase. The distribution CIM model should be able to represent multiphase attributes for the distribution network and devices.

In this research, a data modeling method was proposed to solve the multiphase attribute problem. It is summarized as follows.

- Identify the device that has a multiphase attribute problem and treat it as a composite component. For example, distribution lines, voltage regulators, and distribution loads are multiphase attribute components, and they were treated as composite components when they were modeled.
- Analyze the composition of the composite component, and decompose it to smaller entities. If any of these smaller entities is still a composite component, carry out this step again until all components are fully decomposed. For example, a voltage regulator is decomposed into

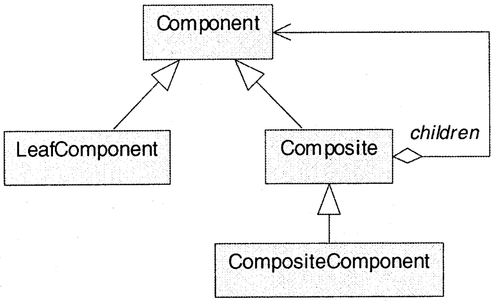

Fig. 3. Composite pattern [9].

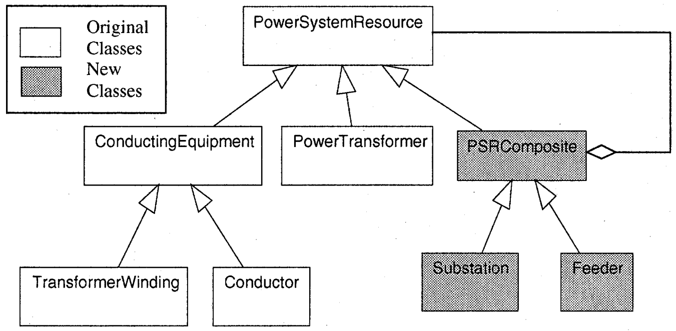

Fig. 4. Previously proposed model for the whole-part relationship [10].

a combination of three components, the transformer winding, the tap changer, and the line drop compensator.

- Analyze each entity and the relationship between them. Model each entity and the whole composite component with appropriate attributes and relationships.

This approach was applied to model distribution lines, distribution loads, and voltage regulators and it solved the multiphase attribute problem in an efficient manner. More details about these models are given in Section IV.

C. Whole-Part Relationship

Electrical distribution typically starts at the substation and continues to the customer meter. It consists of circuits known as the primary feeders or primary distribution feeders. A distribution feeder is a concept of a group of power system elements. A given feeder is made up of a main feeder, branches or laterals, and sublaterals. It is usually sectionalized by reclosing devices and protected by fuses. It is also supported by other devices, like shunt capacitors and voltage regulators. The relationship between distribution substation, feeders, and feeder devices is a whole-part relationship. The distribution CIM model needs to be able to represent this whole-part relationship between distribution components.

The composite pattern (Fig. 3) is a good way to model the whole-part relationship [9]. This model defines both single objects and composite objects. Single objects can be composed into more complex objects, which can be, in turn, composed recursively. In [10], a model (Fig. 4) was proposed to represent the whole-part relationship. In this model, the *PSR composite* class is created to represent power system resources that contain other resources. A *PSR composite* object may have several *conducting equipment* objects or *power system resource* objects as its children as well as other *PSR composite* objects, which may also have *conducting equipment* objects as children. After the model was proposed in [10], there were many discussions in the EPRI's CCAPI task force about the whole-part relationship modeling and a new model was proposed recently in [2]. The concept of the new proposed model in [2] is very close to the model in [10]. This research work proposed a feeder model based on the latest whole-part model defined in the CIM [2]. More discussions of the feeder model are in Section IV.

IV. PROPOSED DISTRIBUTION CIM MODEL

Four models—the line model, the distribution load model, the voltage regulator model, and the distribution feeder model, are proposed in this section. These models are the CIM extensions for the electric distribution system. Necessary modifications are made to the original CIM to meet data requirements for distribution power flow applications.

A. Line Model

The line model in the original CIM defined classes of *conductor, conductor type, wire arrangement*, and *wire type* for any line configurations like three-phase, two-phase, and single-phase [2]. But the attributes defined in the class *conductor* indicate that this model is only for balanced three-phase systems. It uses positive and zero sequence components to describe line impedance. In distribution systems, people cannot use these attributes for asymmetrical three-phase lines, two-phase lines, and single-phase lines. Another problem is that the original line model does not provide enough information for cables. A modified line model for both transmission and distribution lines is proposed. Two major issues are addressed here:

- **Geometric attributes and the electric attributes**. The geometric attributes are basic physical attributes of a power line. They reflect the real world characteristics of a line configuration. The electric attributes are conceptual attributes and can be obtained from the geometric attributes and other information. Transmission and distribution applications may have different requirements for power lines. For example, most transmission applications may only need electric attributes for a line, but distribution applications may need more geometric information of a line. If these two sets of attributes are coupled, it can cause problems. A good way to handle this is to model geometric and electric attributes separately.
- **Cable information**. The model needs more information for the cables. In distribution systems, many lines are made from cables. In the IEEE radial test feeders, the author uses two types of cables, concentric neutral and tape shielded cable, as distribution lines. There are still other types of cables used in distribution systems.

The modified line model represents the impedance in a separate class hierarchy to provide the flexibility for a conductor to have an appropriate impedance representation. Spacing and cables are also modeled to provide geometric and conductor information for power lines. Some classes and attributes defined in the CIM line model are appropriate for distribution modeling purpose. They are reused in the modified line model that is shown in Fig. 5. Several attributes in spacing, overhead

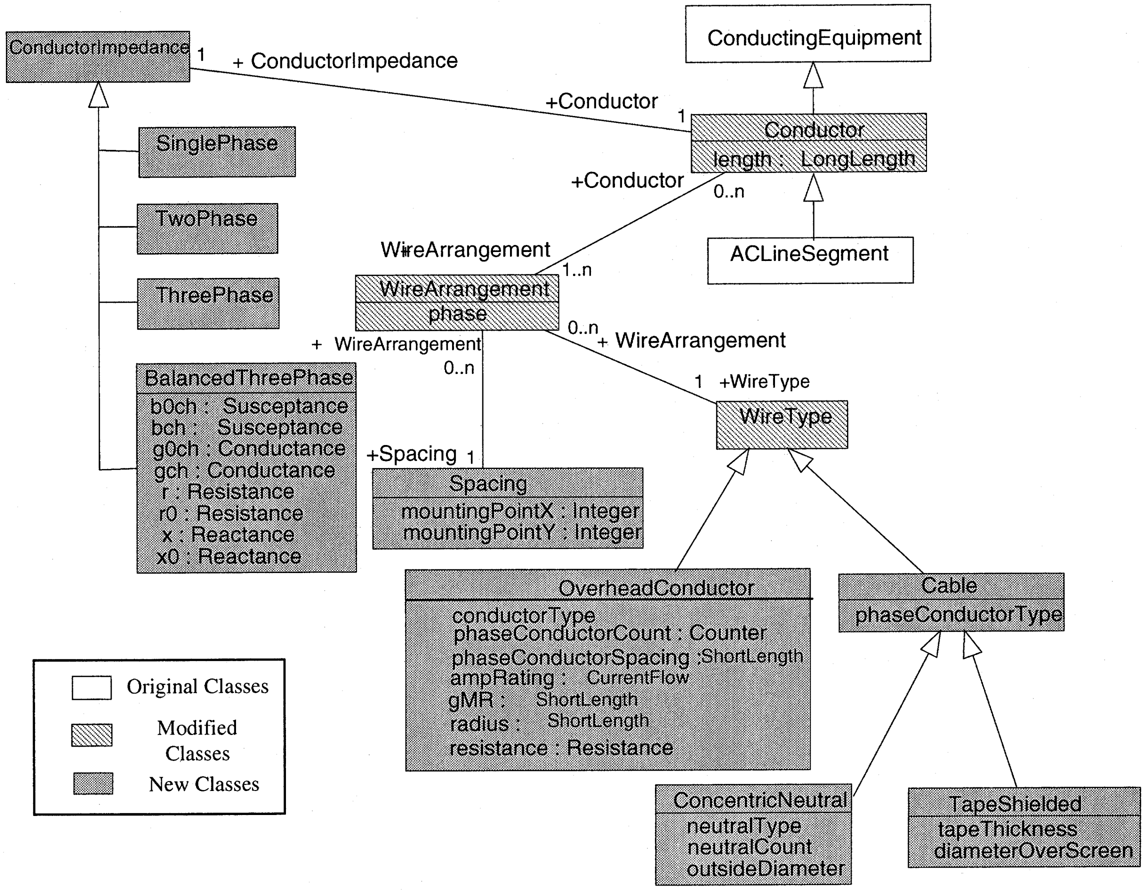

Fig. 5. Proposed modified line model.

conductor, and balanced three phase are reused attributes. Other items, such as phase conductor count and phase conductor spacing, are more appropriate for transmission but remain as part of the overall CIM model.

The basic idea of using this model to represent a power line is to give each phase a wire arrangement with both geometric and conductor information. Using the line 650-632 example again, it is a three-phase four-wire overhead distribution line [6], [7]. The conductor used for each phase in line 650-632 is ACSR 556 500 26/7, and the conductor used for neutral is ACSR 4/0 6/1. In order to represent the line with the CIM model, the following steps are taken:

- create an *ac line segment* object for a distribution line segment—for the example an *ac line segment* object for line 650-632 is set;
- Create a *wire arrangement*-type object for each phase including neutral-four *wire arrangement* objects for phase A, B, C, and neutral phase are represented;
- create spacing type objects for the spacing used in a wire arrangement—this creates four spacing-type objects for each phase's wire arrangement. Notice that, these spacing objects may be used by other wire arrangements.
- create appropriate *wire type* objects for the conductor used in a wire arrangement—this includes two *overhead conductor*-type objects for conductor ACSR 556 500 26/7 and ACSR 4/0 6/1.

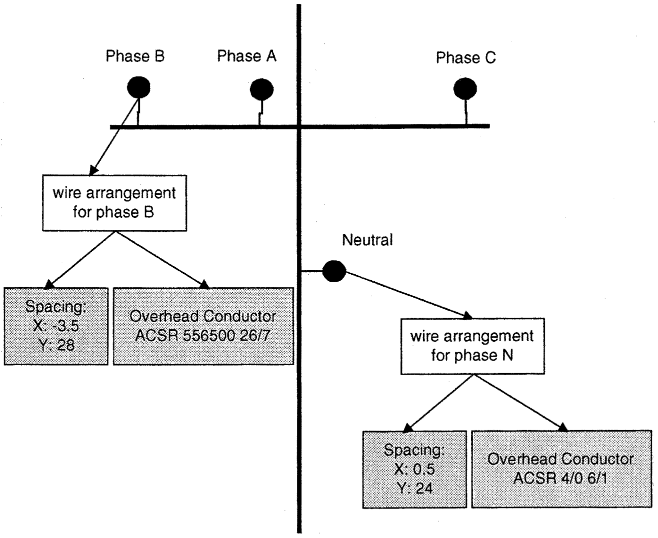

Fig. 6. Representation for line 650-322.

After these above steps, the line 650-632 is represented with an *ac line segment* object that has four *wire arrangement* objects for each phase and neutral. In turn, each wire arrangement has a *spacing*-type object and an appropriate *wire-type* object to show the geometric and conductor information. Fig. 6 illustrates the representation for the line 650-632.

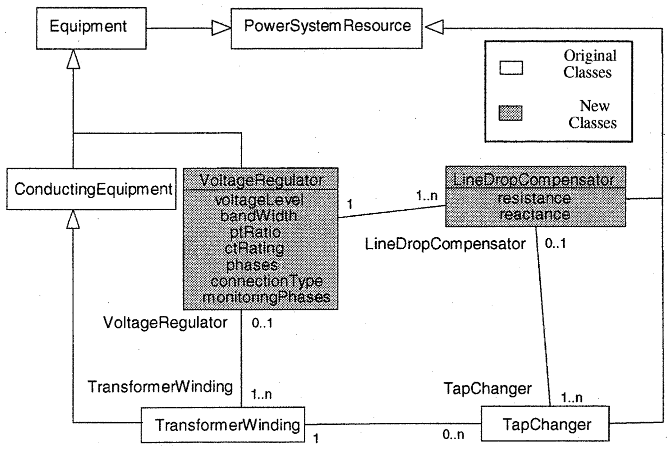

Fig. 7. Proposed voltage regulator model.

B. Voltage Regulator Model

Voltage regulators are commonly used to maintain a constant voltage at the point of utilization. Only step type will be considered here. A step-type voltage regulator is fundamentally an auto-transformer with many taps in the series winding. The automatic voltage changing is achieved by line-drop compensator (LDC) located on the control panel of the voltage regulator. When modeling voltage regulators, the following problems need to be considered.

- The model should be able to represent three-phase, two-phase, and single-phase voltage regulators.
- The model should be able to represent wye, delta, and open delta connections.
- The model should be able to represent tap changer, line-drop compensator, and other characteristics of voltage regulators.

Fig. 7 illustrates the proposed voltage regulator model. The *voltage regulator* defines a template for voltage regulators. It provides common attributes like voltage level, pt ratios, and ct ratios to describe basic characteristics for a voltage regulator. It has a relationship with the class *transformer winding* to describe how a voltage regulator is internally structured. The *line drop compensator* models line drop compensators in a voltage regulator. Attributes, resistance, and reactance describe the equivalent impedance between the regulator and the load center. The relationship with the class *tap changer* provides information about which tap changer the line drop compensator controls.

An example is provided to show how to use the proposed voltage regulator model to represent the voltage regulator in the IEEE 13-node test feeder. It is a three-phase wye connected voltage regulator. Each phase has an individual line drop compensator to control its tap changer. For more details about the voltage regulator, please see references [6], [7]. Fig. 8 illustrates the voltage regulator representation of phase B. Other configurations, such as the open delta regulator, are modeled in the IEEE-37 node test feeder.

The following steps show the procedure to use the proposed voltage regulator model to represent voltage regulators:

- Create a *voltage regulator* object—for the example, a *voltage regulator*-type object for this voltage regulator is created and assigned values for its attributes.

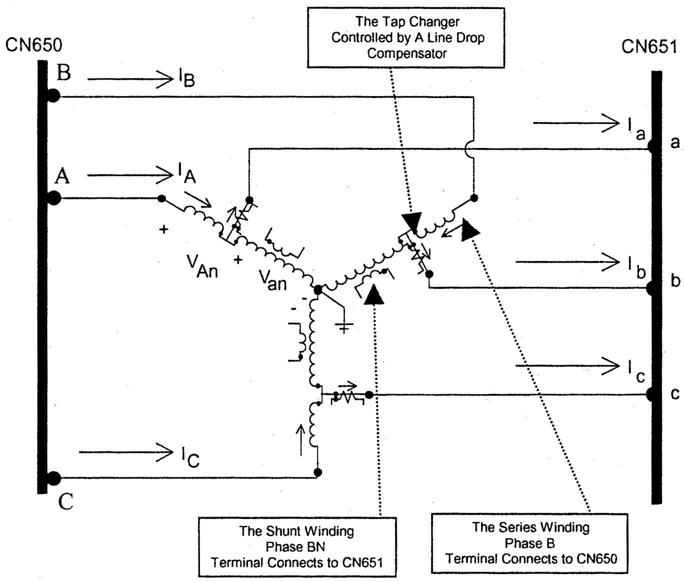

Fig. 8. Voltage regulator representation.

- Create *transformer winding* objects—this step includes six transformer windings for this voltage regulator. A single-phase voltage regulator has two transformer windings, a series winding, and a shunt winding; and they are physically connected. This is a three-phase voltage regulator with three independent phases. The phase for each winding is determined by the attribute *conducting equipment* phases.
- Create a *terminal* object for each winding—a terminal for each transformer winding is set up. Each terminal connects to the right node.
- Create a *tap changer* object for each series winding—each series winding has a tap changer. The example needs three tap changers for the three series winding.
- Create a *line drop compensator* object for each tap changer—three line drop compensators for the three tap changers are set.

C. Distribution Load Model

For the purpose of this research, only a static load model is considered. It uses the load model that describes the relationship between distribution load and voltages in terms of algebraic equations shown in (1). Coefficients a, b, and c represent the portion of constant impedance, constant current, and constant power load, respectively

$$\begin{cases} P = P_0\left(a_p\left(\frac{V}{V_0}\right)^2 + b_p\left(\frac{V}{V_0}\right) + c_p\right) \\ Q = Q_0\left(a_q\left(\frac{V}{V_0}\right)^2 + b_q\left(\frac{V}{V_0}\right) + c_q\right) \end{cases}. \tag{1}$$

The basic requirements for the distribution load are

- The model should be able to represent connectivity (at which point this load connects to the network).
- The model should be able to represent multiphase connection and connection type (three-phase, wye, or delta connected load, single-phase, line to line, line to ground connected load, or distributed load).

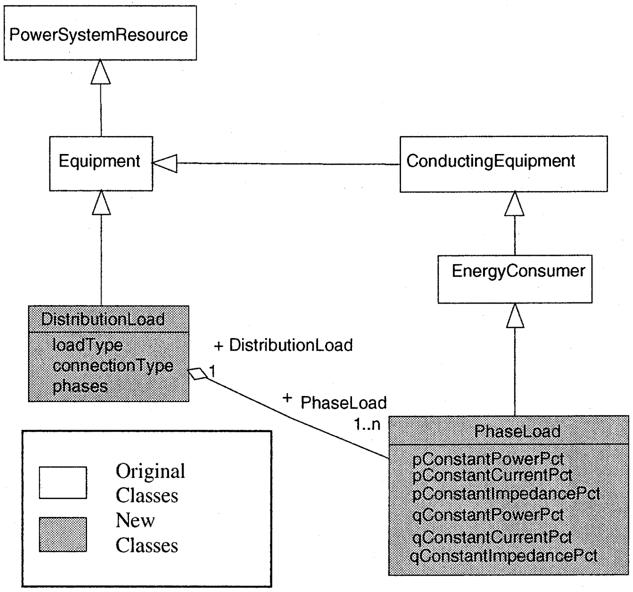

Fig. 9. Proposed distribution load model.

- The model should be able to represent load type (constant power, impedance, or current).
- The model should be able to represent multiphase attributes (three-phase balanced or unbalanced load).

Fig. 9 illustrates the proposed distribution load model. The class *distribution load* is a generic distribution energy consumer. It could be either a composite load of a group of customers or a single energy user. The class *phase load* models load with the unified characteristics. It can be one phase of a multiphase load and also can be a three-phase load with unified characteristics. Its native attributes describe the percentage of constant power, constant current, and constant impedance of a distribution load. The aggregate relationship between *distribution load* and *phase load* allows a distribution load to have any type configuration like single phase, two-phase, or three-phase. Some classes and attributes defined in the CIM load model are also applicable to distribution load modeling requirement. They are reused in the proposed distribution load model. Some attributes of phase load are reused.

D. Distribution Feeder Model

As mentioned before, to model the distribution feeder is to model the whole-part relationship between a composite object and single objects. In the latest CIM model [2], the whole-part relationship is modeled by the equipment container pattern. The feeder model (Fig. 10) was proposed based on this pattern. It is modeled as a subclass of the *equipment container*. This allows the *feeder* to inherit the aggregate relationship between the *equipment container* and the *equipment*, so the *feeder* has the ability to contain any type *equipment* as its member. The major difference between the equipment container pattern and the composite pattern is that the former one does not provide a composite object the ability to contain other composite objects. So the relationship between the *feeder* and the *substation* is explicitly defined in Fig. 10.

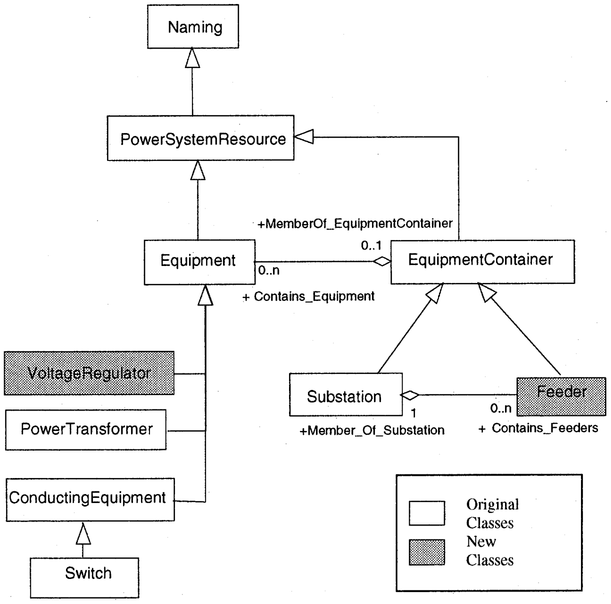

Fig. 10. Proposed feeder model.

V. CIM XML EXPORT TOOL

An important aspect of the standardization of the distribution extensions is the standardization of the import and export of distribution models. One reason why this is important is that the CIM is a logical data model, which may have physical implementations, which vary greatly from vendor to vendor. The approach taken here was to leverage the prior work done by Prof. Kersting in developing IEEE feeder models and the work done by the CIM XML group for standardizing exchanges of transmission models using XML.

The CIM XML export tool was designed for creating CIM XML documents for the IEEE radial test feeders. It takes test feeders as input and generates CIM XML documents. The design of the CIM XML export tool focused on the ability to allow for adjustments after frequent CIM updates. It examined the basic characteristics of CIM models and CIM XML documents. It provided a set of general interfaces, which can minimize the efforts of changing the existing design and implementation when the CIM model gets changed. The CIM XML tool is general for all test feeders. It was implemented in Microsoft Visual C++ 6.0 and used the IBM XML4C XML parser [11]. This research generated CIM XML documents for all test cases including 13-node, 34-node, 37-node, 123-node, and 4-node feeders. The 4-node test feeder provides many cases for testing transformer connections and different types of loads [6], [7]. In this research, CIM XML documents were created for two cases in the 4-node test feeder. Case 1 is three-phase step-down transformer with wye-delta connection. Test case 2 is two single-phase step-down transformers with open wye and open delta connections. Unbalanced load was used in these two cases.

VI. TEST RESULTS

In order to verify that the proposed distribution CIM model is able to represent distribution system data and the created

TABLE I
TEST RESULTS OF ALL TEST FEEDERS

	13 node	34 node	37 node	123 node	4 node	
					Case 1	Case 2
Topology	Correct	Correct	Correct	Correct	Correct	Correct
Lines	Correct	Correct	Correct	Correct	Correct	Correct
Switches	Correct	N/A	N/A	Correct	N/A	N/A
Loads	Correct	Correct	Correct	Correct	Correct	Correct
Capacitors	Correct	Correct	N/A	Correct	N/A	N/A
Voltage Regulators	Correct	Correct	Correct	Correct	N/A	N/A
Transformers	Correct	Correct	Correct	Correct	Correct	Correct

CIM XML documents are logically right, this research implemented a CIM XML import tool for validation check. The basic idea of checking validation of these CIM XML documents is to convert them back into databases (called feeder databases) and compare feeder databases with original Microsoft Excel data sheets, which store the IEEE radial test feeders. The following steps are procedures of checking validation of these CIM XML documents.

- read the CIM XML document and process feeder data;
- import the feeder data to a database;
- compare the database to the original database, which contains the feeder information.

All CIM XML documents were checked through the above steps. Topology for each component, line configurations, conductors, voltage regulators, tap changers, and line drop compensators, transformer and transformer windings, capacitor banks, and switches were checked item by item. Table I summarizes the test results of all test feeders. Details of the tests are available in [12]. The proposed draft for these distribution CIM models and the XML representation of the IEEE PES test feeders are available online at site [13].

VII. CONCLUSIONS AND FUTURE WORK

In order to facilitate enterprise application integration in a utility IT environment, a common data model is needed to describe power system data in distribution networks. This research extended the CIM to the electrical distribution system appropriate for distribution power flow applications. It also provided a set of CIM XML documents based on the IEEE radial test feeders. This research also proposed general data modeling techniques for multiphase attributes and the whole-part relationship modeling.

Currently, the proposed model is under review by several companies. The first job that needs to be done in the future is to let more people review the model and get feedback from them. Then, more work is needed to summarize this feedback and make necessary modifications. In addition, this research work has focused on distribution system data modeling and started from the distribution power flow. It proposed models for distribution lines, distribution loads, voltage regulators, and distribution feeders. Obviously, in order to facilitate the integration within the entire DMS system, a more comprehensive common model is needed to describe every aspect in DMS systems.

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