AC 2011-2687: SMART GRID DEVELOPMENT USING MODELING, DESIGN, SIMULATION, AND DIAGNOSES OF ELECTRICAL DISTRIBUTION NETWORK

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A Course in Smart Grid development using Modeling, Design, Simulation, and Diagnoses of Electrical Distribution Network

Abstract

This paper will present an existing course in smart grid technology and promotes problem solving and innovations. Some topics of interest are: areas in course development, course organization and content; laboratory equipment and experiments; and some concepts in smart grid. After adapting this course, some student's project has already been developed, implemented and assessed. The course structure and contents covers topics on educating students on how to build a smart gird and use advanced computer application software tools for modeling, design simulation, and diagnoses of electrical distribution network systems. Computer software applications and case studies will be used in the classroom for teaching and research of the smart grid in residential, industrial and commercial systems.

Developing a new course

There are a number of concerns and issues addressed for developing a new course in the area of smart grid in power distribution system such as:

1) How to design and simulate the smart grid power distribution network system
2) What are the decision support tools?
3) How to better utilize existing software tools to manage outages in the power distribution networks
4) How to cost-effectively integrate existing information systems so that they work collectively to support business activities such as diagnosis, scheduling and repairs
5) How to teach students to model the smart grid in power distribution network

Course Objectives

The course is developed on selected advanced topics to cover the fundamentals of Smart Grid in Power Distribution Network (PDN) management, including system modeling, system integration, information fusion, and criteria in data base selection and design. The objectives will prepare the students with sufficient background for the concepts of PDN management with enough hands-on experience to understand and model a PDN system. After the completion of this course, the students will poses sufficient theoretical background to do independent study and research on PDN system and smart grid related topics.

Course Structure and Content

The following table describes the structure of the course and its content in detail. Even though this material is designed for a quarter long system, it can easily be expanded to a semester long system.

Duration	Description of the course	Application Software
Week 1	Smart Grid and PDN Overviews • From Generation to Distribution	
Week 2	Existing PDN vs. New PDN systems • Problems with existing PDN systems • PDN System Analysis	
Week 3	Substation Design • Bus • Substation Components • Using CAD software tool to build the Standards	Power Simulator PSCAD AutoCAD
Week 4	Switching Selection and Design • Remote Vs. Manual • Relays • Breakers • Sensors and their allocation	SKM
Week 5	Load Analysis and Calculations • Load analysis • Load distribution	CYMDIST
Week 6	PDN Models • PDN components • Model selection criteria • Software tools such as UML (Unified Modeling Language) for models	UML Visio Rational Rose TogetherSoft
Week 7	Information Fusion (Data Systems) • SCADA (Supervisory Control and Data Acquisition System) • CIS (Customer Information System) • GIS (Geographic Information System) • GPS (Global Positioning System) • AVL (Automatic Vehicle Locator) • IVR (Interactive Voice Response) and Trouble Calls	MySQL ArcGIS ArcView ArcSDE
Week 8	PDN System Integration and management • Database selection criteria • Database Design • OLEDB, ODBC	MySQL PC Oracle Access
Week 9	Decision Support Tools • Switching coordination • System reconfiguration • Load dispatching • Fault Analysis • Fault Recovery	Any available COTS
Week 10	Students Project Presentations	

Course Learning Goals

After successful completion of this curse the students will be able to:

- Describe the concepts of: Smart Grid, Electrical Power Distribution Network System, and recognize its importance and characteristics.
- Perform system analysis with an existing PDN and therefore identify the problems and suggest improvements.
- Understand the operation of substation and be able to identify all associated components.
- Utilize computer software tools to design standards for substation.
- Select appropriate switching devices for modeling a PDN.
- Apply computer software tools for load analysis and calculations.
- Model and design an appropriate PDN system using software languages such as UML.
- Describe information fusion and its impact in PDN, such as SCADA, CIS, IVR, AVL, GIS, GPS, etc.
- Integrate system's components, leading to database selection and design.
- Identify decision support tools and the requirements such as fault analysis and recovery.

Review of Power Distribution Network Architecture

The power distribution systems, regardless of their size, tend to have similar concerns with respect to information technology. Most utilities depend upon computer systems for managing their maps thru using Geographic Information Systems (GIS). Many have Supervisory Control and Data Acquisition (SCADA) systems for remotely managing sub-stations and main switches. Most have Interactive Voice Recognition Systems (IVR) which automatically logs the calls of customers reporting outages. The difficulties come when these systems have to work together, for example in the control room during an outage. A dispatcher watches the trouble call and SCADA systems for any sign of malfunction, and coordinates the repair actions. The dispatcher is actually performing much of the work of integrating and fusing information together and manually synthesizes the solutions. It is possible to support these tasks with systems designed to perform the integration and fusion automatically. The solution synthesis can also be supported with appropriate tools.

The overall power system distribution is introduced at the beginning of the course. The topology of a typical power distribution network at the main feeder level just coming out of the substation typically would look like figure 1. This figure represents the topology of the electrical grid system at the high voltage level and deals only with the switching devices such as Circuit Breakers (CB) and Remote Switches (RS). The filled rectangle represent closed remote switched and empty rectangle represents open switches. This will help later on to build the model of the power distribution system at the high voltage level with the associated switching devices.

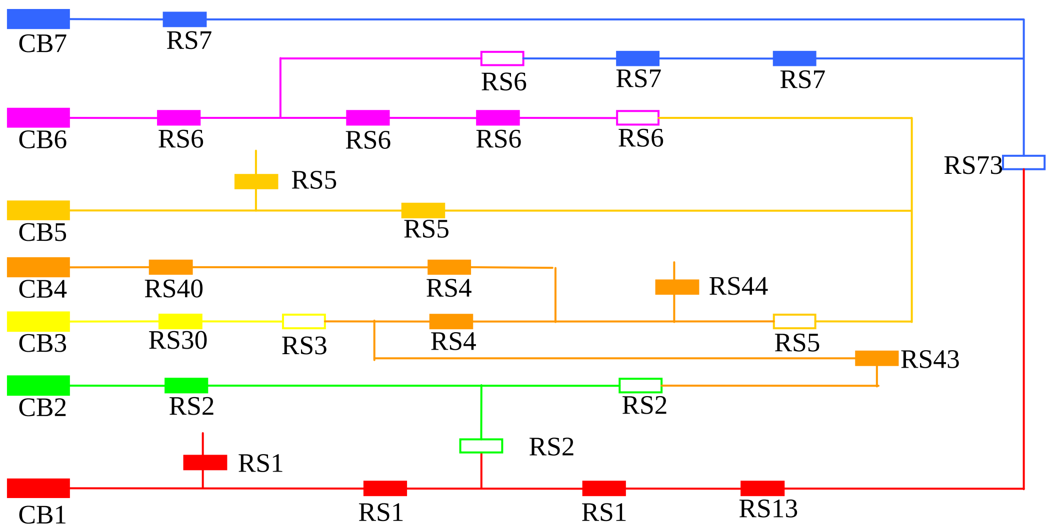

Figure 1. Power Distribution Network at the main feeder level

The overall architecture of a typical power distribution network that combines both the high voltage line and low voltage line is illustrated in figure 2. The starting point is at the substation[1] level. The power is first generated at the power generation plant and then transmitted thru transmission lines into the substations. The challenge here is to teach the students how to model the power distribution system from the substation all the way to the consumer levels. Figure 2 suggests that a typical power is being distributed from the starting point as the followings: Substation (SUB) to Circuit Breaker (CB) to Remote Switch (RS) and/or to Manual Switch (MS). The power flow at different points (with respect to each phase) will be distributed to different sections passing thru sectionalizing switches. Fused (F) are provided at different places of the lateral levels for safety and protection. At this point, the transformers (T) are tapped to the consumers' load (LD). All the connections between the components are established thru conductor lines (LN).

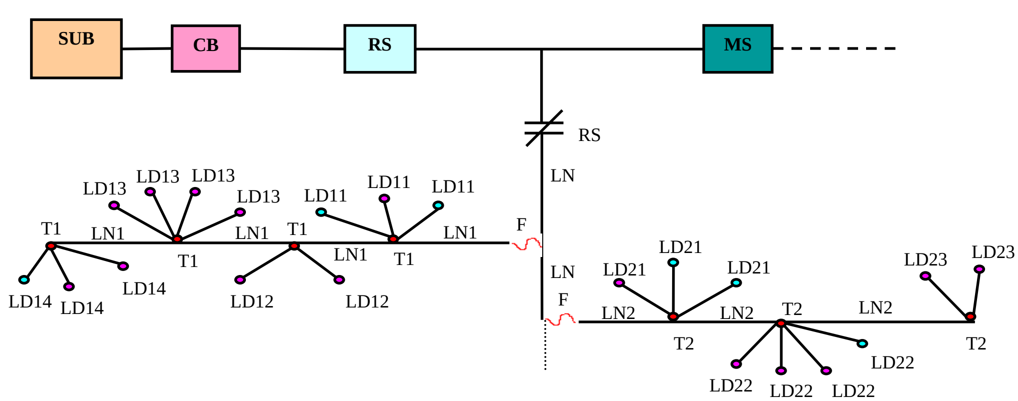

Figure 2. Overall architecture of Energy Distribution Network

Database Systems

The data systems provide additional information about the network configuration, the customers, and the health and fault status of the circuit. The status information can be thought of as instrumentation of the circuit. For example, a SCADA system will provide remote monitoring of currents, voltages, and switch positions of various remote circuit components (direct measurements). An Automatic Vehicle Locator (AVL) system will locate the construction and repair crew on the field, therefore, making scheduling easier. An Interactive Voice Response (IVR) or trouble calls system will respond to customer phone calls and log service outages (observations of customers). A Customer Information System (CIS) database contains address and contact information of customers, service location, and billing information (additional information about the network and customers) that can be used in matching phone numbers of trouble calls to locations in the network. Figure 3 illustrates the components of a data system.

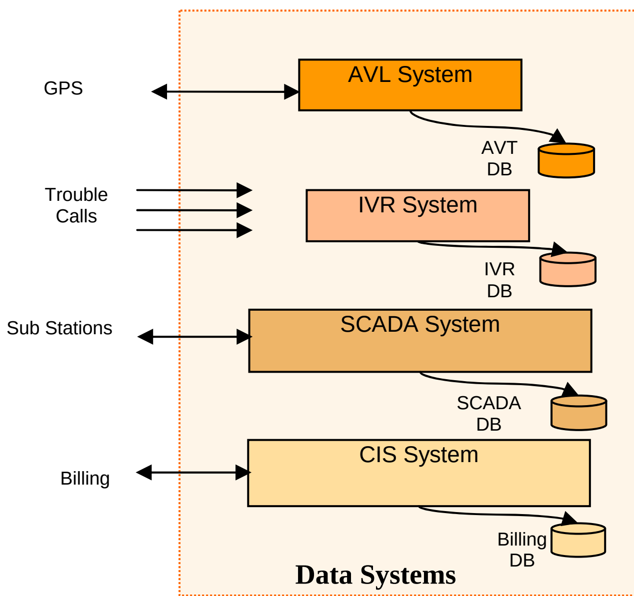

Figure 3. Data Systems for a typical Energy Distribution Network

Table below is a summary of some application software that was used in the course to aid the students in learning the materials related to the data systems. The prices are considered to fit the budget of a typical student. However, some other software may be researched and considered.

System	Description	Company	Software	Price
AVL	Automatic Vehicle Locator using GPS	Q-GPS Trimble	LAS 3100 Lassen	$240 N/A
IVR	Interactive Voice Response and trouble calls	NCH	IVM	$ 84
SCADA	Supervisory Control And Data Acquisition	FastTrak	FTAlarm FTDataWin	Free Demo
CIS	Customer Information System	MySQL	mysql	Free

Facility Management Systems

These systems are usually present in electrical utilities from a number of vendors. A Geographic Information System (GIS) contains a model of the circuit topology, i.e. where components are?, how they are inter-connected?, and includes some service or customer information. Since a goal might be to promote open systems concepts, the overall integration framework is designed to work with GIS systems which store the circuit topology information in a standard format, such as a commercially available database (SQL Server, Oracle, Sybase, etc), or in files with either a published format or with standard access drivers available (OLEDB, ODBC, etc). Facility Management (FM) systems are used to design, maintain, control, and generally manage the network. Examples are work order management systems, which are used to update the GIS model as the circuit is extended and maintained, and load analysis packages. Refer to Figure 4 for an illustration of a facility management system.

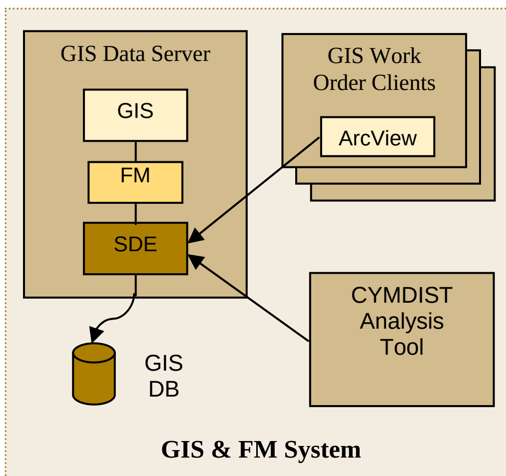

Figure 4. GIS and FM Systems for a typical Energy Distribution Network

Table below is a summary of some application software that was used was used in the course to aid the students in learning the materials related to the GIS and FM systems. Some other application software may be researched and considered.

System	Description	Company	Software	Price
GIS	GIS software for topology	ESRI	ArcGIS	Free demo
FM	Facility Management	ESRI	ArcGIS	Free demo
SDE	Spatial Data Engine	ESRI	ArcSDE	Free demo
ArcView	View of work order	ESRI	ArcView	Free demo
CYMDIST	Distribution System Analysis	CYME	cymdist	Free demo

Decision Support Tools

The decision support tools are a set of software application that are available either thru COTS (commercially off the shelf) and/or designed and hand-written by the students. The decision support tools are basically the brain of the system that makes intelligent and sometimes complex decisions. Some of these tools are:

1) Diagnostic and Outage analysis
2) Switch coordination
3) Repair planning
4) Restoration time
5) Catastrophic analysis
6) Network integration decisions
7) Load analysis
8) Phase analysis
9) Load dispatching
10) Facility management
11) Crew scheduling
12) Network reconfiguration

Simulation and Modeling

A well defined "modeling paradigm" for electric power management network is an important task that must be accomplished initially. A modeling paradigm is the language with which one can represent the system models. This will allow to express the system structure, components, and functionality in a comprehensive form. Therefore, to properly model any large, complex electrical power distribution system, a model builder must describe the system's entities, relationships, and power flow clearly. This modeling environment must constrain the model builder to create syntactically and semantically correct models. Before any system is built, issues such as what is to be modeled, how the modeling is to be done, and what types of analyses are to be performed, must be formalized.
Before proceeding with the paradigm definition, one must think about interconnectivity of components, which as a whole will form the topology of the electric power distribution network. The Unified Modeling Language[2] (UML) is an excellent candidate to define the paradigm. One can build a meta-model (a model of the modeling paradigm) using UML class diagrams to specify the objects (components), attributes (features), and their relationships. For modeling user interface, any graphical modeling representation tools may be applied such as Microsoft Visio, IBM Rational Rose, Borland Togethersoft, GME[3], etc. In this course the UML was used because it is a well-known and widely accepted modeling language, and end users can more easily participate and contribute to the modeling language specification process.

Assessment of the students' learning

In student's assessment, several methods was exercised such as: small projects and demonstrations, weekly homework problems, final team project and presentations. Students were required to conduct formal presentation and be reviewed by their classmates and instructor.

Even though the students demonstrated their knowledge of subject through a variety of means (assignments, oral presentation, written report etc.), use of assistive, adaptive or other technologies were encouraged to ensure that students can accurately express what they know and learned. A clear guidelines and/or evaluation rubrics for all course assignments or activities was provided. Finally, an assessment of the entire student's work was collected and thru sufficient feedback, the future course improvement and challenges was discussed.

Assessment form: The following evaluation was distributed to each student. The students will fill out the surveys at the beginning of the term and revisit the form and fill out surveys at the end of the term.

Criteria for Assessment	**Before taking this course**	**After taking this course**	**Comments (required for each person)**
PDN Knowledge	2	5	
Smart Grid Knowledge	1.5	4	
Software tools knowledge	1	4	
Project leadership	2.5	5	
Team communication	3	4	
Overall team work	4	5	
Any comments for course improvement	" I like to see another course in continuation of this subject" " I learned what PDN and smart grid means" " I now know what a life cycle of project means" "Team projects really helps"		
Total	**14**	**27**	
Student Name			
Team Name	Smart Grid		
Date	Spring 2010		
Please use: 5= excellent, 4= very good, 3= good, 2= average, 1= poor			

To allow students to demonstrate their knowledge of subject matter through a variety of means (oral presentation, written report etc.) such as:

How do I ask students to express their knowledge?

- To give an oral report on weekly basis
- To present some working examples
  - Charts, design flow graph, Design Algorithm
- To show a demo
  - Object is moving forward
- Short quizzes
  - Explain different phases of system development life cycle.

To encourage the use of assistive, adaptive or other technologies to ensure that students can accurately express what they know.

– The students will use small circuit boards to build a workable prototype of the subsystem.
– They will use Microsoft project to schedule and plan their work.
– They will use power point to aid their oral presentation.

To provide a clear guidelines and evaluation rubrics for course assignments the following guidelines for evaluation of course assignments and activities was used:

Subject Area	Percentage
Innovation ideas	15%
Planning and Requirements	10 %
Analysis and Feasibility	10 %
Design and Development	10 %
Implementation and Testing	10 %
Documentation	5 %
Transfer of technology	15%
Presentation	5 %
Self Evaluation	5 %
Communication and team work	5 %
Availability	5 %
Reflection	5 %

Conclusion

By developing this course the students will have enough understandings and techniques to take on the challenges that are facing today's power distribution network systems. As the size of the smart grid system grows, the problem of decision making on day to day operations becomes obvious. The scaling issue has presented a problem and therefore a challenge to the smart grid. It is very important for students who are planning to study in the areas of smart grid to be well informed and introduced to the basics and fundamentals of power distribution network system.

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