Object-Oriented Expert System Estimates Line Ampacity

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Introduction

In a competitive power supply business environment, line ampacity predictions are required by electric power utilities for economic generation planning, contingency planning, security analysis, and for normal and emergency operation of electric power systems. The line ampacity system featured in this article calculates ampacity from general purpose National Weather Service (NWS) forecasts and does not require additional hardware on power lines. By designing the ampacity expert system with objects and rules, it can be easily implemented in small and large electric companies.

The Line Ampacity System is a PC/Windows-based, power-line ampacity, expert system program for the estimation of line ampacity during steady state, dynamic state and transient conditions. It was developed by the application of artificial intelligence using object-oriented knowledge base design of the power line environment. The expert system provides hourly values of line ampacity up to seven days in advance and is used for the operation, planning, and design of transmission and distribution lines at all voltages. The program is an economical line ampacity system that does not require the installation of additional transmission line hardware, conductor temperature sensors, meteorological sensors or telecommunication system, and is easily implemented in all geographic regions.

Line Rating Methods

Electric power companies generally assume constant power line capacity by assuming conservatively the values of ambient temperature, wind speed and solar radiation required in the calculation of ampacity. Most common assumptions are that ambient temperature is 40 degrees Celsius, wind speed is 2 feet per second, there is a clear sky, and the maximum conductor temperature is 80 degrees Celsius. During favorable weather conditions when ambient temperature is lower than the assumed maximum or when wind speed is higher than the assumed minimum or during cloudy conditions, higher line ratings are possible without exceeding the maximum temperature of the conductor. For these reasons, many utilities have started adapting line ratings to actual weather conditions. Dynamic line rating systems are also proposed that take into account the heat capacity of conductors. Existing real-time line ampacity systems require continuous input of data from line temperature sensors, meteorological sensors and/or on-line connection to a weather bureau and line current. Sometimes elaborate telecommunication systems are also necessary to bring data from remote locations to a host computer where line ampacity is evaluated.

Program Descriptions and Innovations

The new line ampacity program provides an alternative method of obtaining line ampacity by synthetic generation of weather data. It does not require real-time weather data or real time conductor temperature measurements. If online connection to a weather bureau or conductor temperature measurements are available, they are useful but not essential to the implementation of the program. By a unique system of objects, rules, and user input, the line ampacity system eliminates the need for additional hardware on power lines or the installation of dedicated telecommunication system to determine line ampacity. In the system, hourly values of meteorological data comprising of ambient temperature, wind speed and solar radiation are self generated by weather station objects by fitting general- purpose NWS forecast data to the stored weather patterns of the region. NWS data is easily obtained from daily newspapers, or weather services.

The principal innovations and benefits of the new line ampacity system are:

- Integrated system: provides ratings of all lines in a region during steady-state, dynamic, and transient conditions.

- Forecasting capability: forecasts hourly values of line ampacity up to seven in advance

- Implementation: easy to implement in all geographic regions, and does not require real-time data or additional line hardware.

- Operability: easy to use PC/Windows program with state-of-the-art graphical user interface and user configurable power line and conductor objects.

- Visual representation: graphic display of ampacity, showing power line and weather information in a map.
- Expert system capability: offers advice and explanation of messages

- Reliability: line ratings are based upon National Weather Service forecast from several locations along the route of the power line.
- Cost: cost-effective PC software based system.

Session Windows

One of the principal objectives of the line ampacity system is to realize an economical line ampacity system by greater user participation. Session windows are designed to facilitate users of the program to obtain all the functionality of the program in a logical manner. For example, ampacity is forecast in the Ampacity Forecast session window, as shown in the Figure 1. Similarly, steady-state, dynamic-state and transient analysis are carried out in their respective session windows. If weather information is desired, it is displayed in a cartogram session window.
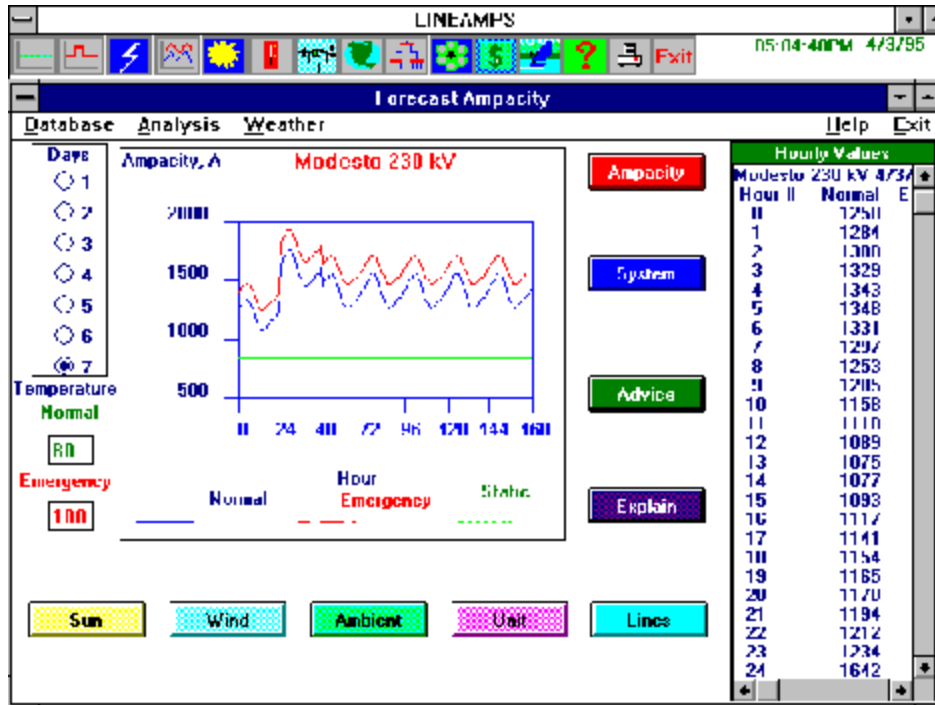
Figure 1. Ampacity Forecast session window.

Data Requirement

User input to the program is facilitated by point-and-click options provided by the graphical user interface design of the program in the PC/Windows environment. Because the program does not require real-time conductor temperature data or real-time meteorological data, greater user participation is required to obtain the best results. Expert rules of ampacity ensure the correctness of data entered to the program and are designed to create greater interest amongst users. The following data is required from the user.

- Power line conductor data and line design parameters. The geographic locations of the line are specified by entering the coordinates of the points through which the line passes.
- General purpose meteorological forecast by the national weather service.

The task of data entry has been made simple and accomplished in very little time. For example, weather data required for California is input in less then twenty minutes. The required data is available from daily newspapers or other weather services.

Object Oriented Design

The power line ampacity system lends itself very well to object-oriented design where power lines, meteorological stations, conductors, analytical models and the system for the manipulation and display of data are objects. It has resulted in more efficient code, less

programming and the advantages of modularity and reusability of objects. The object model of the new line ampacity system is shown in Figure 2.
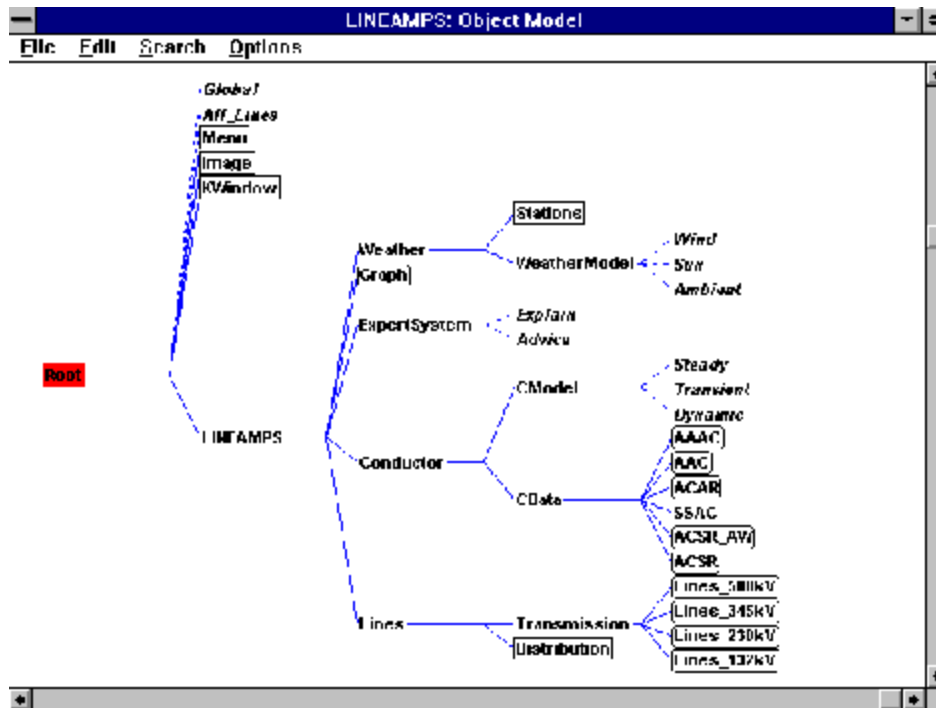

Figure 2. Object model of the line ampacity system.

Object Model Overview

The power line ampacity system was developed by using the Kappa-PC™ object-oriented application development environment, which has its own programming language. The line ampacity object model is composed of a hierarchical structure of objects. They comprise classes, sub-classes, and instances, which are known as objects. The power line ampacity system consists of both tangible and intangible objects. Examples of tangible objects are power lines, conductors, and weather stations. Analytical models steady-state, dynamic, and transient ampacity are examples of intangible objects.

Structure of Objects

The power line system uses object-oriented modeling in which power lines are grouped under a general class of lines and specific types of lines are further divided into sub-classes of lines. For example, there may be sub-classes of voltage levels such that all lines with the same voltage belong to the same sub-classes and inherit class characteristics. A power line having a certain voltage level is an instance of that voltage sub-class. New instances of lines automatically inherit class attributes. Proper classification of line objects is useful to modular program design, which also results in faster response time to user needs.

Data and Methods

Objects contain two basic types of information: data describing the characteristics of the object, and methods that specify what the object can do. Methods have been developed in the line ampacity with uniformity of interface and specialization. The same method in different objects responds to the same messages in different ways. For example, when a message is sent to the ampacity method of the analytical objects, they all perform the same function of evaluating ampacity. This is referred to as uniformity of interface. The evaluation of ampacity is carried out in different ways depending on whether ampacity is desired for steady-state, dynamic-state, or transient conditions. This is referred to as method specialization.

Self-Generation of Ampacity

An attractive feature of objects is that they can act on their own, because data and methods that operate on the data to achieve the desired functionality are contained within the same object. This feature is well suited for the implementation of this invention where the power line object has the capability to calculate its own ampacity and to draw itself on a map. Likewise, the self-generating weather station objects are capable of generating their own weather data. The power line object has a method that uses its own data to calculate ampacity. Hourly values of weather data (ambient temperature, wind speed, wind direction, and solar radiation) that are required to calculate ampacity are generated by methods in the weather object. Coordination between objects is achieved by a message passing mechanism. In the above example, weather station objects near power lines send messages containing weather data to the power line object. In the line object, there are virtual weather sites located at strategic locations along the route of the line. These virtual weather sites receive their data from the nearest weather stations. Power line ampacities are calculated at each virtual weather site, and a method determines the minimum hourly values of ampacity for up to 7 days in advance. Figure 3 shows a power line object, associated weather stations, weather sites along the route of the line, wind direction, and the manner in which messages are sent to the weather sites from the weather stations.

Object Descriptions

Each object contains data describing the object's characteristics and method that specify what the object is capable of doing.

Power Line Objects

The power line object contain attributes of the overhead power line and methods required for the calculation and display of line ampacity. New power line objects may be created by the user. In addition to the calculation of ampacity, the power line object also draws itself in the cartogram window, as shown in Figure 4. By drawing the line in a map, one obtains a clear picture of the power line and its environment.
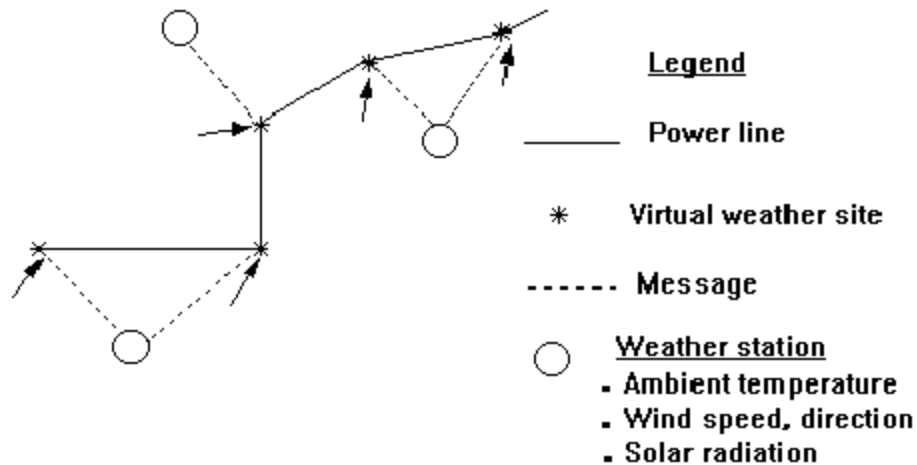
Figure 3. Power line, weather stations, weather sites, and wind direction.

Weather Objects

Weather stations belong to the weather station object class which contains meteorological data and the geographic information of the location. Weather station objects also contain the methods for self generation of weather data which are adjusted to NWS forecast. In Figure 4, weather station objects are shown on the left hand side window, and actual weather data can be seen in the cartogram window on the right.

Conductor Objects

Data of different types of commonly used conductors are stored in conductor objects for easy access by the user. As with power line objects, users also have the ability to create new conductors that are not found in the above databases. The program is flexible and does not limit or restrict the user in the application and development of power line ampacity.

Display Objects

The screen displays are objects created by using an object-oriented, knowledge-based, development system, and the displays make use of ready-to-use screens, graphics, icons, list box, buttons and menus for the Windows operating system. The resultant code is efficient, manageable, and upgraded easily.
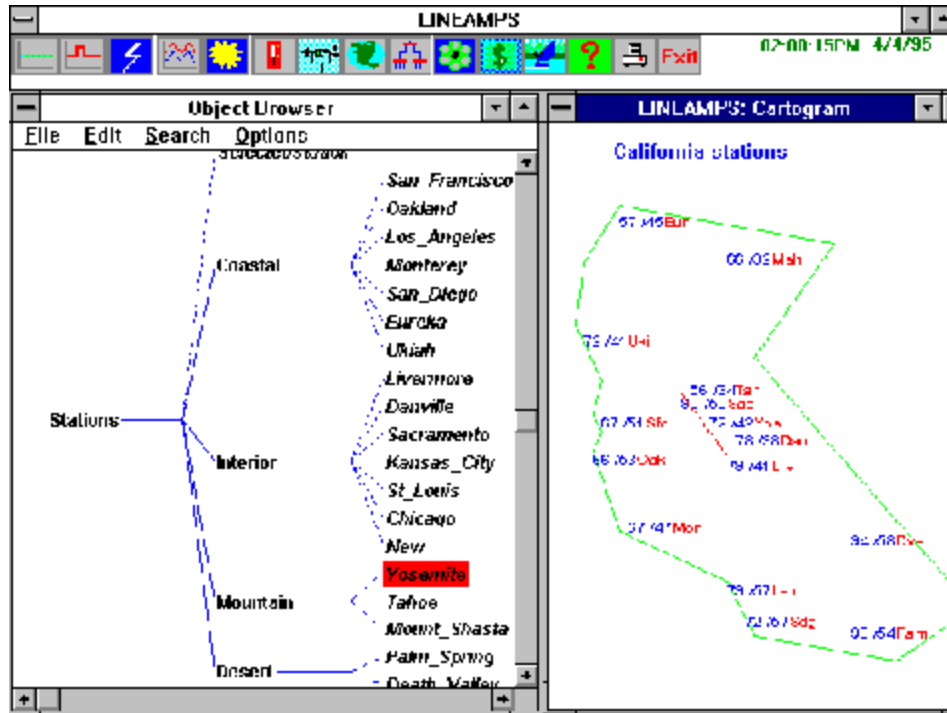
Figure 4. Weather station objects and cartogram window.

Analytical Objects

At the present time, the program comprises the following analytical objects.

- Steady-state ampacity model
- Dynamic-state ampacity model
- Transient ampacity model for short-circuit and lightning currents
- Weather models to forecast ampacity

Expert Hypertext Links to Objects

Expert help is available to the user from the online user's manual. Context-sensitive help files are directly invoked from objects and rules making the program a true expert system. The on-line reference manual is designed to facilitate use of the program and may be used as an educational tool for the understanding and application of power line conductor thermal ratings. The online Help system is shown in the Figure 5.

Figure 5. Help system session window.

Rules

Rules are a simple means to represent knowledge and are used for reasoning with data in the objects. The line ampacity system uses rules to provide expert advice and detailed explanation of results and rule generated messages. Rules also ensure the correctness of data entered by the user before sending messages to the objects for action. If errors are detected, a message is posted on the screen and remedial action is facilitated by the advice-and-explain feature of the program. Some examples of rules are:

Rule 1, Conductor temperature: If the specified conductor temperature is greater than the maximum allowed for the conductor type then advise user.

Rule 2, Ambient temperature: If ambient temperature is greater than conductor temperature then advise user.

Rule 3, Emissivity: If the value of emissivity is equal to or less than zero or greater than one then advise user.

Rule 4, Dynamic temperature: If steady state pre-load current result in maximum conductor temperature then advise user.

New rules are easily added to the expert system as new rules are learned about utility-specific functions, allowing easy upgrade in the future.

Theory and Results

Conductor Thermal Rating

Conductor thermal rating is calculated by the solution of the conductor heat balance equation:

$$M \cdot Cp \cdot dTc/dt + Qcon + Qrad = Qgen + Qsolar$$

During steady-state conditions, the equation is:

$$Qgen + Qsolar = Qcon + Qrad$$

Where M is the mass of the conductor, (kg/m); Cp is the specific heat of conductor, J/(kg·°K); Tc is the conductor temperature, degrees C; $Qgen = I^2Rac$ is the heat gained by joule heating, (W/m2); I is the conductor current, Ampere; Rac is the ac resistance of the conductor, (ohm/m); Qsolar is the heat gained by solar radiation, (W/m2); Qcon is the heat lost by convection, cooling due to wind, (W/m2); Qrad is the heat lost by radiation, (W/m2). The steady state solution is used for analysis and also to forecast hourly values of ampacity. Direct solution of the differential equation (1) are used in dynamic and transient analysis.

Ambient Temperature and Wind Speed Model

Hourly values of ambient temperature and wind speed are generated within the weather object from Fourier series functions. These functions are obtained by fitting historical weather data of the region using Fast Fourier Transformation (FFT). The Fourier series is determined by spectral analysis and by the method of least squares. Data generated by the Fourier series model compared well to actual measurements.

Solar Model

Solar radiation is forecast by an analytical model based on sun's position at the time of day, day of year, latitude and longitude of the line location, and sky condition. Solar radiation is calculated within weather station objects by:

$$S(t) = Sb(t) + Sd(t), W/m2$$

Where S(t) is the total solar radiation at time interval t, and Sb(t), Sd(t) are the beamed and diffused solar radiation respectively.

Ampacity Model

Hourly values of steady state conductor ampacity is calculated by:

$$I = \sqrt{\frac{Q_{con} + Q_{rad} - Q_{solar}}{R_{ac}}}$$

Results obtained by the application of the above model can be seen in the Ampacity Forecast session window that was shown in the Figure 1.

Program Benefits

The development of a simple line rating computer program is significant, because the program can be used by small as well as large electric companies for economic energy transfer. The new program is an economical line ampacity system that is simple to install and operate and does not require additional hardware other than a standard PC. Electric power companies can maximize the use of existing and future overhead power lines, realize energy conservation by economic energy transfer, and enable environmental protection by the deferment of capital investment required for the construction of new overhead power lines.

Low Cost

Research has shown considerable savings in utility power system operation by dynamic and weather dependent line ratings. Utility cost savings are made possible by the deferment of capital required to build new lines or to upgrade existing lines. Research shows that in most cases transmission/distribution refurbishment costs can be deferred by about 10 years by the implementation of a dynamic and weather dependent line rating system. The program makes use of general purpose weather forecast data available from daily newspapers or other weather services.

Higher Line Ratings

Estimates of the average increase in line capacity is in the range of 10 to 40 percent by use of the new program and may be determined more accurately from utility line rating standards and weather conditions in the geographic region of the utility. The reliability of existing systems is also improved by a reduction in line outages.

For Further Reading

- "Self generating power line ampacity system", by Anjan Deb. US patent pending.

- "PG&E's ATLAS (Ambient Temperature Line Ampacity System) Transmission Line Dynamic Thermal Rating System", by L. Cibulka, W. J. Steeley and A. K. Deb, CIGRE 1992, Paris, France.

- "Economic Evaluation of Dynamic Thermal Rating by Adaptive Forecasting," by J. F. Hall, A. K. Deb, IEEE Transactions on Power Delivery, Vol. 3, No. 4, October 1988, pages 2048-2055.

- "A new thermal rating approach: The real time thermal rating system for strategic overhead conductor transmission lines, part I, general description and justification of the real time thermal rating system," Davis M.W., IEEE transactions on power apparatus and systems, vol. 96, May/June 1977.

- Object Oriented Design with Applications, by G. Booch.

Acknowledgment

Biography

Anjan K. Deb is power line consultant and inventor of LINEAMPS. He received the BSEE from MACT Regional College of Technology, India in 1973, and the equivalence of master's degree in electrotechnique from the National Conservatory of Arts and Professions, Paris, France, 1980. From 1985 to 1993 he worked as a consultant at Pacific Gas & Electric Company R&D department, where he has successfully implemented a real-time transmission line rating system. He has previously worked in electric power and manufacturing companies in Algeria, France and India. He is a member of the IEEE, SEE and CIGRE. His E-mail address: akdeb@aol.com