FINAL REPORT DOCUMENT
FOR A
KNOWLEDGE BASED MODEL
OF
ELECTRIC UTILITY OPERATIONS

Los Alamos National Laboratory

RFP NO. 9-LY2-W6083

(Task 3 Extension)

by

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MASTER

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1.0 Introduction

The idea of the extension in task 3 is to provide a documentation and help capability for an analyst using the developed expert system running in CLIPS. This capability is provided through a separate package running under the WINDOWS Operating System and keyed to provide displays of text, graphics and mixed text and graphics that explain and elaborate on the specific decisions being made within the knowledge based expert system.

The CLIPS program automatically transmits a pointer address to the graphics system and it will in turn select a set of graphics that are pertinent to the question. For example, the text below was generated by the Adapted Model Knowledge Based System Delivered In Task 2:

A breaker has tripped within the system. One of the following may result from a breaker trip.

1. Overload
2. Voltage Limit Violation
3. System Islanded
4. Load Lost
5. Security Analysis shows a contingency overload
6. Security Analysis shows a contingency voltage violation

To see the explanation the user moves the mouse to activate the graphics program and after clicking, the first graphic display associated with the above menu will appear (in this case the graphics display and text will have information about a breaker opening event).

As long as the user stays within the graphics system, the CLIPS expert system is suspended and does not run further. The user can move around the subset of displays associated with the particular menu last seen in the expert system, or the user can go back to an index display and bring up any other graphic subset.

When the user has seen the graphics desired, the expert system can be reactivated by moving the cursor back to the CLIPS window. At this point, the user may wish to go ahead and answer the question posed in the expert system and move further deeper into the knowledge base, or the user may wish to escape this line of reasoning and return to the top of the menus for that subject. The graphic index screens and the graphic forms contain the expert system logic statements for the

users reference. The user can use the expert system to guide a particular exercise in power system operations to a conclusion, or they can use the graphic system alone to explore the documentation of the knowledge base itself.

2.0 Technical Scope of the Explanation System

The explanation system is keyed to the particular menu being displayed by the expert system. These are referred to as "display subsets" throughout this document. A display subset is a grouping of displays that are to be brought up from a specific expert system menu and they are directly reachable from one to the other through hyper regions and buttons. To go to another subset requires the user to return to the display *form finder* and then select a new subset.

The explanation system consists of the following types of displays:

- Text Only Displays

- Graphic Only Displays

- Mixed Text and Graphic Displays

The text only displays contain the text imbedded in the CLIPS knowledge base in the form of "Documentation" text. This text was placed in the knowledge base to assist a user who wishes to read it or alter it to know what the knowledge base designed to cover at that point. In the task 3 system, the documentation text is expanded to provide more complete explanations as needed.

The graphic displays are based on a diagram level system (see 2.3 below) which allow the user to go from a general view of the power system to a specific view of the component or situation in question.

Mixed text and graphic displays have text to explain the accompanying graphic diagram(s).

Each of the displays have buttons and/or hyper regions that the user can touch with the cursor to select new displays (see section 2.1). In addition, pressing the combination of CTRL+M sends the display system back to its master form and resets the entire graphics system. CTRL+M may be pressed at any point in the application.

2.1 Features Supported on the Displays

- Hyper Regions

- Hyper Text

Buttons

The hyper regions are keyed to the subject matter for the display subset. The hyper regions and buttons allow the user to move from display to display within the display subset and then select the display index to move to a new display subset. The selection order of selection is based on a logical progression through the displays. The diagram below illustrates the concept of a display subset and the ability to move about within that subset using the hyper regions and buttons.

2.2 The Index Display within the Explanation System

The display system consists of many display subsets that each cover a particular technical explanation keyed to the expert system. There is also an index subset that allows the user to search for any topic covered in the display system and to go to that subset by selecting an index entry. The user must move to the index in order to select a new subset.

The following diagram illustrates the use of the index display(s) to select new display subsets:

2.3 Diagram Levels

The diagrams (with or without text) are Rules set up to allow the user to move logically downward from general detail about a power system to diagrams about specific events and components. In the diagram below a power system is presented as a set of generators connected to transmission substations (boxes) and

eventually to load substations:

By selecting the generator in the high level diagram above, the user can obtain a more detailed picture of the generation substation as shown here:

Finally, the user is asked to pick a specific generation problem, in this case low voltage, whereupon a diagram of a generation voltage control system is seen with further instructions:

The philosophy here is to allow the user to move between diagrams with only cursor movement and selection of those topics that are in question at the time.

3.0 Implementation

3.1 The Adapted Model Knowledge Based System is linked through pointers to

the Explanation Module.

The CLIPS program, "Adapted Model Knowledge Based System," developed in task 2, has been modified to include an interface to pass messages to the windows application, by depositing values into files readable by the windows graphic control program. The data provides a pointer to select the starting graphic in the windows graphic control program. The graphic control program links related graphics screens containing graphics, text boxes and controls. Graphics

screens are selected from within the WINDOWS environment using the graphics control program. Chaining is implemented through the use of "buttons" which select graphics to be displayed. The graphic control program provides chaining throughout the subset of graphic displays.

The CLIPS program is started from within WINDOWS operating in the enhanced

mode. When the graphic control program is active the CLIPS program is suspended until control is returned. Therefore, the entire system operates under the WINDOWS environment.

3.2 Diagram Indexing

The graphics control program will have the capability to select any graphic through a main index and provide chaining within a subset related by logic. This will provide the user with the ability to review the graphics much like browsing through a book. Text boxes are an integral part of the graphics screens and are present whenever the graphic is viewed.

4.0 Operation

It is assumed the user has a knowledge of DOS and WINDOWS operations. The user should also be familiar with the basic operations of Object Vision and the "Knowledge Based Model of Electric Utility Operations" developed earlier. The Object Vision tutorial is recommended to become familiar with the product.

4.1 Computer Setup Before Loading Program

The "Knowledge Based Model of Electric Utility Operations" (*the model*) was

developed to operate under the rule based expert system, "CLIPS 5.1," developed by the Software Technology Branch, NASA/Lyndon B. Johnson Space Center. To operate correctly the model requires the use of a DOS extender program to operate beyond the 1 MB barrier. "286DOS - Extender" published by PHAR-LAP was used in conjunction with the memory manager "386MAX" published by QUALITAS Inc. to provide the memory management support required to operate CLIPS 5.1 in protected mode.

Object Vision, published by Borland International, is required to operate the Explanation system. A runtime version of Object Vision should suffice to operate the applications. However, the product has not been tested with the runtime version.

In addition to the use of a memory manager and a DOS extender, CLIPS 5.1 must be compiled to operate in the protected mode. "*CLIPSEX.EXE*" is a protected mode compiled version of CLIPS and must be used with this program.

All files required to operate this application must be copied into the same directory located on a hard drive. The Object Vision program does not need to reside in the same directory with the application files. The files required are contained in four compressed files delivered on two 3.5" high density floppies. Disk 1 contains *PCLIPSEX.ZIP*, the *CLIPSEX* files necessary to run CLIPS, *PMODEL.ZIP*, the "Knowledge Based Model of Electric Utility Operations" *.CLP files, *PEXPLN_1.ZIP*, the Object Vision *.OVD files, and documentation files. Disk 2 contains *PEXPLN_2.ZIP*, the Object Vision *.OVG files.

Documentation is supplied in *Word for Window 2.0*, *Microsoft publisher*, and ASCII text formats. The latter omits graphics and most formatting.

4.2 Instructions for operating the program:

After all files have been expanded into the same directory (Requires approximately 4MB of disk space) *WINDOWS* is started in accordance with normal operating procedures. Following standard procedures, open a DOS Window within *WINDOWS*.

CLIPS is started within the DOS window. With the PHAR-LAP DOS extender installed the active directory is changed to the directory containing *CLIPSEX.EXE* and the *.CLP files, (see above), the command sequence is, assuming the active directory is CLIPS51: (keyboard responses are shown in bold type)

C:\CLIPS51>run286 clipsex

CLIPS (V5.1 10/02/91)

Clips (nn.nnMB)> (load "start.clp")

(The program will respond with several commands)

Clips (nn.nnMB)>(reset)

Clips (nn.nnMB)>(run)

(The program will load the remaining rules and display the initial menu)

Use the **alt+enter** command to switch to the window display mode, placing *COMMAND* running within a window. The Program Manager or File Manager should be accessible.

It is recommended that a group containing Object Vision application *MASTER.OVD* be created to simplify the process of opening the Object Vision application *MASTER.OVD*. Object Vision is started and the *MASTER.OVD* application is opened. All other applications are accessible from *MASTER*.

4.2.1 Operating in the Explanation module:

Object Vision is started by opening the *MASTER.OVD* application. The user is presented with the choice of operating in conjunction with the expert system or in a stand alone (Index) mode. When the user chooses to operate with the expert system the ASCII files are read and the application pointed to by the contents of *file.txt* is opened. The ASCII file containing the selected form name is also read and the *formname* field is updated. Upon loading, an Object Vision application will present its *form finder* form. The *form finder* form contains three active areas. A click anywhere on the map will cause the application to re-read the ASCII files and to update the *formname* and *requested file* fields. A box, "**Go To Form**", causes the form named in the *formname* field to be selected. The selected form is then opened as an overlay of the current form, if the file name contained in the *requested file* field is the same as the current application file name. If it is not, the application named in the *requested file* field is opened. The second box "**Go To Index**" opens the application's index form or forms. From the index form any form within the application may be selected. Each of the form entries in the index contain the expert system logic relative to the rule executed. Each of the forms also contain the corresponding rule name and logic that was executed within the expert system.

4.2.2 Operating in the Expert system module:

The user is presented with questions or choices and the response to them cause rules to execute. Rules have corresponding explanations within the Object Vision

application. With the expert system window and the object window both open and sharing the screen space, activating the DOS window by clicking the cursor in its space transfers control to the expert system. The keyboard is used to respond to the expert system questions. Whenever the expert system displays a rule, moving the cursor back into the Object Vision area switches control back to the application. If the *form finder* form is displayed, clicking on it will cause the pointer fields to be updated and then a click in the “Go to Form” will select the form pointed to. In the event that a form other than the *form finder* is the top form when control is transferred to the expert system, it is necessary to close all forms before a new pointer is executed.

4.2.3 Program termination:

The Object Vision applications may be safely terminated with any form being displayed. The Object Vision menu is used to terminate the program.

The expert system should be terminated through its ordinary shut down procedures of exiting from the main menu. Terminate CLIPS with the (exit) command before attempting to exit Windows before shutting down the system.

4.3 Design Notes

Object Vision is organized into “applications” and “forms.” One of the fundamental applications for Object Vision is to provide a Graphical User Interface for dBase and Paradox database applications. However, the program contains logic tools that enable it to act as a tool to manage a set of graphics.

Each application (program or file) contains a “stack” of “forms.” Each form can contain text, fields, embedded graphics and referenced graphics. This application makes extensive use of the referenced graphic capability. The use of the referenced graphic capability allows a graphic to be used in many different forms which reduces file size.

The explanation system is divided into seven applications. The following table shows the Object Vision applications (*.OVD), the number of forms in each and the number of different graphics files (*.OVG) in each. The application and graphics files must both be present within the same working directory. The appendix contains a complete table of contents of the forms contained in each application and the graphics files that are attached to them. The appendix also contains a printout copy of each of the forms.

As the expert system executes its rules the knowledge base keeps two ASCII

files (*file.txt* and *form.txt*) located within the working directory updated. The program state (Control, Protection, Transmission, etc....) is deposited in the ASCII file *file.txt*. As each rule is executed the rule name is deposited in the ASCII file *form.txt*.

The pointer files *file.txt* and *form.txt* are read only from the *form finder* form of each application and from the *MASTER.OVD* application.

Selection of the Index mode presents the user with a menu to directly select any of the Object Vision applications.

In both the expert system mode and the index mode subsequent forms are added

Application	Number of forms	Number of Graphics files
Master.OVD	2	0
Tran_Evt.OVD	75	20
Restore.OVD	23	7
Gen_Evt.OVD	84	28
Norm_Evt.OVD	38	25
Ctrl_Evt.OVD	16	1
Prot_Evt.OVD	31	19

to the desk top as they are opened. Forms are removed when they are closed.

During the operation of the model, infrequently and with no detectable pattern or cause the system suffered a lockup, requiring a reboot. In no case were any files corrupted by this phenomenon. The lockups occurred within CLIPS and did occur both when operating within the Windows environment and in DOS. Since the occurrences were infrequent and not apparently repeatable no effort was expended to find the cause.

4.3.1 Use Of Passwords In Object Vision

Each of the Object Vision applications is protected from accidental modification by the use of a password. The password only affects the ability to modify the application forms. In the even access to the form modification is necessary, open the application from the Object Vision menu instead of the pointer file. The open dialog box contains a field that requests a password. Filling in the correct password will open the application in an edit mode instead of the operational mode. The password is the application file name without the extension. Upon completion of the editing process, save the application with its current name (any change in the file name will affect the Object Vision/expert system interface), using the password again.

In the event an Object Vision application is closed by the use of the Object Vision menu command, the change in the contents of the pointer fields is seen as a modified file by Object Vision, and will ask to save the file. The question should be answered **"no"**.

4.3.2 Tools used to generate the forms and graphics

The graphics process: The graphics screens were constructed using CoralDraw. The CoralDraw screen was ported into Object Vision through the graphics import facility using the Windows Clipboard utility. This process produces the graphics file (*.OVG) instead of pasting directly into the Object Vision form. The size of the graphic and its location within the form are adjusted to the requirements of the individual form.

Equations: The equations found throughout the program were generated in Microsoft's "Equation Editor" utility packaged with "Word for Windows". "Equation Editor" does not contain a file structure of its own, each screen is pasted into the application via the "Clipboard" utility. The equations were either pasted into the CoralDraw drawing and then into the *.OVG file or directly into the *.OVG file.

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Appendix A

Generator Event Graphics

Contents of GEN_EVT.OVD:

Index

Gen_menu

Rule2 » Text

Rule3 » Text

Rule4 « rust31.ovg

Rule5 « Rule102.ovg

Rule6 « Rule102.ovg

Rule7 « ace_cht.ovg

Rule8 » Text

Rule9 « Rule9.ovg

Rule100 « Rule102.ovg

Rule101 « Rule102.ovg

Rule102 « Rule102.ovg

Rule103 « Rule103.ovg

Rule104 « Rule102.ovg

Rule105 « Rule105.ovg

Rule106 « Rule105.ovg

Rule107 « Rule605.ovg

Rule108 « Rule605.ovg

Rule109 « Rule142.ovg

Rule110 « Sum.ovg

Rule111 « Chart.ovg

Rule112 « Chart.ovg

Rule113 « Rule130.ovg + usmap.ovg

Rule114 « Rule130.ovg + usmap.ovg

Rule115 « Rule115.ovg

Rule116 « Rule116.ovg

Rule117 « Rule142.ovg

Rule118 « Rule142.ovg

Rule118a « Rule142.ovg

Rule119 « Rule142.ovg

Rule120 « Loadcht.ovg

Rule121 « Loadcht.ovg

Rule122 « Loadcht.ovg

Rule123 « Loadcht.ovg

Rule124 « Rule130.ovg

Rule125 « Rule130.ovg

Rule126 « Rule142.ovg

Rule127 « Rule142.ovg

Rule128 « Loadcht.ovg

Rule129 « Rule142a.ovg

Rule130 « Rule130.ovg

Rule131 » Text

Rule132 » Text

Rule133 » Text

Rule134 « Rule134.ovg

Rule135 « Rule134.ovg

Rule136 « Rule136.ovg

Rule137 » Text

Rule138 « Rule142.ovg

Rule139 » Text

Rule140 « Rule142.ovg

Rule141 » Text

Rule142 « Rule142.ovg → Rule142a «
Rule142a.ovg + Rule142c.ovg

Rule143 » Text

Rule144 » Text

Rule145 « Rule605.ovg

Rule146 « Rule142.ovg

Rule147 « Rule147.ovg

Rule147a « Rule147.ovg

Rule148 « Rule134.ovg

Rule148a « Rule134.ovg

Rule149 « Rule136.ovg

Rule149a « Rule136.ovg

Rule150 » Text

Rule151 → Rule151x « Rule142.ovg

Rule151a → Rule151x « Rule142.ovg

Rule151b » Text

Rule151c » Text

Rule152 « Rule159a.ovg + Rule159b.ovg +
Rule159c.ovg

Rule153 « Page79b.ovg → Rule159a.ovg +
Rule159b.ovg + Rule159c.ovg

Rule154 Rule159a.ovg + Rule159b.ovg +
Rule159c.ovg

Rule155 « Page79r.ovg

Rule156 « Balance.ovg

Rule157 » Text

Rule158 » Text

Rule159 « Page79b + Rule159a

Rule160 « Page79b + Rule159a

Rule161 « Rule159a.ovg + Rule159b.ovg +
Rule159c.ovg

Rule162 « Page79r.ovg

Rule163 » Text

+gen menu "The generation initial events menu" (gen evt menu display)	+Rule100 "Outline 1.1" (state generation state) (on line generation capacity greater than the load)	+Rule104 "Outline 1.1.1.2" (state generation state) (on line generation capacity greater than the load) (on line generation output less than the load) (frequency low emergency)
Rule2 "Generation event abnormal frequency" (event abnormal frequency)	+Rule101 "Outline 1.1.1" (state generation state) (on line generation capacity less than the load) (system-data frequency decay threshold ?low freq breakpoint)	
Rule3 "Generation event control error" (event control error)		+Rule105 "Outline 1.1.1.3" (state generation state) (on line generation capacity greater than the load) (on line generation output less than the load) (frequency low dropping) (system-data regulation requirement ?amount)
+Rule4 "Generation event derating" (event derating)	+Rule102 "Outline 1.1.1.1" (state generation state) (on line generation capacity greater than the load) (on line generation output less than the load) (system-data frequency decay threshold ?low freq breakpoint)	
+Rule5 "Generation event failure" (event failure)		
+Rule6 "Generation event maintenance outage" (event maintenance outage)		
+Rule7 "Generation event off control" (event off control)		+Rule106 "Outline 1.1.1.3.1" (state generation state) (frequency low dropping) (regulation sufficient)
Rule8 "Generation event reserve too low" (event reserve too low)	+Rule103 "Outline 1.1.1.1.1" (state generation state) (on line generation capacity greater than the load) (on line generation output less than the load) (frequency low stable)	+Rule107 "Outline 1.1.1.3.2.1" (state generation state) (frequency low dropping) (regulation insufficient)
+ Rule9 "Generation event var problem" (event var problem) (system-data voltage min1 ?threshold1) (system-data voltage min2 ?threshold2)		
		Continued
		Close

+Rule108 "Outline 1.1.1.3.2.2" (state generation state) (frequency low dropping) (regulation insufficient) (neighbor assist yes)	+Rule112 "Outline 1.1.2.1.1" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start yes)	+Rule115 "Outline 1.1.2.1.4" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start no) (neighbor backup no) (system-data public appeal load reduction ?load reduction)	
+Rule109 "Outline 1.1.1.3.2.3" (state generation state) (frequency low dropping) (regulation insufficient) (neighbor assist no)	+ Rule113 "Outline 1.1.2.1.2" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start no)	+ Rule116 "Outline 1.1.2.1.5" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start no) (neighbor backup no) (public appeal yes)	
+Rule110 "Outline 1.1.2" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (system-data reserve min ?level)			
+Rule111 "Outline 1.1.2.1.1" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum)	+Rule114 "Outline 1.1.2.1.3" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start no) (neighbor backup yes)		
		Continued	Close

+Rule117 "Outline 1.1.2.1.6" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start no) (neighbor backup no) (public appeal yes) (voltage reduction yes)	+Rule118A "Outline 1.1.2.1.6" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start no) (neighbor backup no) (public appeal yes) (voltage reduction yes) (interruptible load insufficient)	+Rule121 "Outline 1.1.2.2.2" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load decreasing)	
+ Rule118 "Outline 1.1.2.1.6" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start no) (neighbor backup no) (public appeal yes) (voltage reduction yes) (interruptible load sufficient)	+Rule119 "Outline 1.1.2.1.7" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve less than minimum) (quick start no) (neighbor backup no) (public appeal yes) (voltage reduction yes) (interruptible load no)	+Rule122 "Outline 1.1.2.2.1.1" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load increasing)	
		+Rule123 "Outline 1.1.2.2.1.2" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load increasing) (generation available yes)	
	+Rule120 "Outline 1.1.2.2.1" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum)	Continued	
		Close	

+Rule124 "Outline 1.1.2.2.1.3" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load increasing) (generation available no)	+Rule127 "(1.1.2.2.1.6) Generation state interruptible load 3" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load increasing) (generation available no) (neighbor assist no) (interruptible load yes)	+Rule129 "Outline 1.1.2.2.1.8" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load increasing) (generation available no) (neighbor assist no) (interruptible load no)
+Rule125 "Outline 1.1.2.2.1.4" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load increasing) (generation available no) (neighbor assist yes)	+Rule128 "Outline 1.1.2.2.1.7" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load increasing) (generation available no) (neighbor assist no) (interruptible load no)	+Rule130 "Outline 1.2.1.1.1" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping)
+Rule126 "Outline 1.1.2.2.1.5" (state generation state) (on line generation capacity greater than the load) (on line generation output equal to the load) (reserve greater than minimum) (load status load increasing) (generation available no) (neighbor assist no)		Rule131 "Outline 1.2.1.1.1" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist yes)
		<div>Continued</div> <div>Close</div>

Rule132 "Outline 1.2.1.1.2" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no)	+Rule135 "Outline 1.2.1.1.3" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no) (gas turbines available no) (hydro available yes)	+Rule138 "Outline 1.2.1.1.5" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no) (gas turbines available no) (hydro available no) (pumped storage available no)
Rule133 "Outline 1.2.1.1.2" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no) (gas turbines available yes)	+Rule136 "Outline 1.2.1.1.4" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no) (gas turbines available no) (hydro available no)	Rule139 "Outline 1.2.1.1.5" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no) (gas turbines available no) (hydro available no) (pumped storage available no) (interruptible load yes)
+Rule134 "Outline 1.2.1.1.3" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no) (gas turbines available no)	Rule137 "Outline 1.2.1.1.4" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no) (gas turbines available no) (hydro available no) (pumped storage available yes)	
		<div>Continued</div> <div>Close</div>

+Rule140 "Outline 1.2.1.1.6" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low dropping) (neighbor assist no) (gas turbines available no) (hydro available no) (pumped storage available no) (interruptible load no)	Rule144 "Outline 1.2.2.1" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (system-data tie flow max ?max)	+Rule147 "Outline 1.2.2.1.2.2" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes)
Rule141 "Outline 1.2.1.1.7" (load shed activated)	+Rule145 "Outline 1.2.2.1.1" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state within limit)	+Rule147A "Outline 1.2.2.1.2.2" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes) (gas turbines available yes)
+ Rule142 "Outline 1.2.1.2" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low emergency)	+ Rules146 "Outline 1.2.2.1.2.1" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded)	+ Rule148 "Outline 1.2.2.1.2.3" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes) (gas turbines available no)
Rule143 "Outline 1.2.1.2.2" (load shed activated)		
<div>Continued</div>		<div>Close</div>

+Rule148A "Outline 1.2.2.1.2.3" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes) (gas turbines available no) (hydro available yes)	+Rule149A "Outline 1.2.2.1.2.4" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes) (gas turbines available no) (hydro available no) (pumped storage available yes)	+Rule151 "Outline 1.2.2.1.2.6" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes) (gas turbines available no) (hydro available no) (pumped storage available no) (wheeling customer rescheduled)
+ Rule149 "Outline 1.2.2.1.2.4" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes) (gas turbines available no) (hydro available no)	Rule150 "Outline 1.2.2.1.2.5" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes) (gas turbines available no) (hydro available no) (pumped storage available no)	+Rule151A "Outline 1.2.2.1.2.7" (state generation state) (on line generation capacity less than the load) (on line generation output less than the load) (frequency low stable) (tie flow state overloaded) (voltage reduction yes) (gas turbines available no) (hydro available no) (pumped storage available no) (wheeling customer rescheduled) (interruptible load yes)
		<div>Continued</div> <div>Close</div>

<p>Rule151B "Outline 1.2.2.1.2.8"</p> <p>(state generation state)</p> <p>(on line generation capacity less than the load)</p> <p>(on line generation output less than the load)</p> <p>(frequency low stable)</p> <p>(tie flow state overloaded)</p> <p>(voltage reduction yes)</p> <p>(gas turbines available no)</p> <p>(hydro available no)</p> <p>(pumped storage available no)</p> <p>(wheeling customer rescheduled)</p> <p>(interruptible load no)</p>	<p>+Rule155 "Outline 1.3.1.1.3"</p> <p>(state generation state)</p> <p>(voltage low)</p> <p>(reserve less than minimum)</p> <p>(switchable capacitor available no)</p>	<p>+Rule162 "Outline 1.3.2.1.3"</p> <p>(state generation state)</p> <p>(voltage within limit)</p> <p>(reserve less than minimum)</p> <p>(switchable capacitor available no)</p>
	<p>+Rule156 "Outline 1.3.1.1.4"</p> <p>(state generation state)</p> <p>(voltage low emergency)</p>	<p>Rule163 "Outline 1.3.2.2"</p> <p>(state generation state)</p> <p>(voltage within limit)</p> <p>(reserve greater than minimum)</p>
	<p>Rule157 "Outline 1.3.1.1.8"</p> <p>(load shed activated)</p>	
	<p>Rule158 "Outline 1.3.1.2"</p> <p>(state generation state)</p> <p>(voltage low)</p> <p>(reserve greater than minimum)</p>	
<p>Rule151C "Outline 1.2.2.1.2.9"</p> <p>(load shed activated)</p>	<p>+Rule159 "Outline 1.3.2"</p> <p>(state generation state)</p> <p>(voltage within limit)</p> <p>(system-data var reserve min ?min)</p>	
<p>+ Rule152 "Outline 1.3.1"</p> <p>(state generation state)</p> <p>(voltage low)</p> <p>(system-data var reserve min ?min)</p>	<p>+Rule160 "Outline 1.3.2.1.1"</p> <p>(state generation state)</p> <p>(voltage within limit)</p> <p>(reserve less than minimum)</p>	
<p>+ Rule153 "Outline 1.3.1.1.1"</p> <p>(state generation state)</p> <p>(voltage low)</p> <p>(reserve less than minimum)</p>	<p>+Rule161 "Outline 1.3.2.1.2"</p> <p>(state generation state)</p> <p>(voltage within limit)</p> <p>(reserve less than minimum)</p> <p>(switchable capacitor available yes)</p>	
<p>+ Rule154 "Outline 1.3.1.1.2"</p> <p>(state generation state)</p> <p>(voltage low)</p> <p>(reserve less than minimum)</p> <p>(switchable capacitor available yes)</p>		
		<div>Close</div>

The generation system is the source of power in a power system and failures of generating units are serious operating problems. Generating units can suffer from loss of control, a derating (operating at less than full output), failure (shutdown of the unit), a maintenance outage where the unit is shut down to fix a problem or to do normal maintenance work), or there may be problems associated with all the units taken together such as low reserves or VAR supply problems.

+gen menu "The generation initial events menu"
(gen evt menu display)

Close

It is critical that the generation and load balance one another at alltimes. If the load and generation are not equal the frequency begins to move away from 60 hz. In this rule, the generation capacity is greater than the load so there is sufficient generation capacity on line, but the generation output is below the load so the frequency is declining.

**Rule2 "Generation event abnormal frequency"
(event abnormal frequency)**

Close

It is critical that the generation and load balance one another at all times. If the load and generation are not equal the frequency begins to move away from 60 hz. The utility industry adopted the term Area Control Error or ACE too apply to the instance of a generation-load mismatch. In this rule, the generation capacity is greater than the load so there is sufficient generation capacity on line, but the generation output is below the load so the frequency is declining.

Rule3 "Generation event control error"
(event control error)

Close

Derating of a generator means that it can no longer put out as much power as it is rated to deliver. This can happen when the unit has a failure of some piece of auxiliary equipment. When a unit is derated, it must lower output and there is a danger too little generation on line to supply the load.

The principal components in a fossil fueled power plant.

Rule4 "Generation event derating"
(event derating)

Close

When a generator fails and has to be taken off line the remaining generating units must be able to make up for the loss without too much drop in frequency. Usually the measure of how much spare on line generation is the reserves carried by the system.

Rule5 "Generation event failure"
(event failure)

Close

When a generating unit is taken offline for maintenance, there is usually enough generation left since this is a planned event. However, if the maintenance outage was not planned (e.g., if the unit suffered a failure and the decision was made to take it off line and perform the maintenance activities as well as fix the failed component), the system could suffer a generation deficit.

Rule6 "Generation event maintenance outage"
(event maintenance outage)

Close

When a generator is off control, it will not respond to raise or lower commands to control frequency and this could be dangerous when frequency is deviating far from normal.

Rule7 "Generation event off control"
(event off control)

Close

59.9

60.0 Hz

60.1

FREQUENCY

Close

When reserves are low there is no actual emergency since the generation still is capable of meeting the load. However, if there is one more generator failure the total capacity of the remaining generators may be less than the load and an actual emergency will result in which the generation is less than the load.

Rule8 "Generation event reserve too low"
(event reserve too low)

Close

If there is insufficient var generation available, the generators on line will not be able to maintain the system voltages and the entire network is in danger of collapse.

Rule9 "Generation event var problem"
(event var problem)
(system-data voltage min1 ?threshold1)
(system-data voltage min2 ?threshold2)

Close

If the generation capacity is sufficient to meet load, the operator still has a problem if the present output from all the generators is less than load and cannot be raised quickly enough to meet the load.

Rule100 "Outline 1.1"
(state generation state)
(on line generation capacity greater than the load)

Close

If the on line generation capacity is below the load, frequency falls is important. If it is slowly decreasing there may be hope of averting trouble, if the frequency falls very fast there is little an operator can do to save the system.

Rule101 "Outline 1.1.1"
(state generation state)
(on line generation capacity less than the load)
(system-data frequency decay threshold ?low
freq breakpoint)

Close

If the generation capacity is sufficient to meet load, one still has a problem if the present output from all the generators is less than load and cannot be raised quickly enough to meet the load.

Rule102 "Outline 1.1.1.1"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output less than the load)
(system-data frequency decay threshold ?low freq
breakpoint)

Close

A dangerous condition exists if the frequency drops and levels off. The system could collapse quickly if load is not shed and new generation brought on line.

Rule104 "Outline 1.1.1.2"
(state generation state)
(on line generation capacity greater than
the load)
(on line generation output less than the
load)
(frequency low emergency)

Close

MW
Output

If frequency is low, the operator must assess the ability of on line generation to bring it back up. If possible, the generation can simply bring up the frequency and no emergency will exist, otherwise the operator will have to shed load and/or start new generation.

Rule105 "Outline 1.1.1.3"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output less than the load)
(frequency low dropping)
(system-data regulation requirement ?amount)

$$\text{Regulation} = \sum_{\text{all on line units}} \frac{dP}{dt} \Delta t$$

Close

Operator makes assessment of generator ability to raise
ge

MW
Output

Rule106 "Outline 1.1.1.3.1"
(state generation state)
(frequency low dropping)
(regulation sufficient)

$$\text{Regulation} = \sum_{\text{all on line units}} \frac{dP}{dt} \Delta t$$

Close

If the generation on the utility

sy
fr
re
sh
m
sy

Rule107 "Outline 1.1.1.3.2.1"
(state generation state)
(frequency low dropping)
(regulation insufficient)

Close

Operator purchases neighbor's power to balance load.

Rule108 "Outline 1.1.1.3.2.2"
(state generation state)
(frequency low dropping)
(regulation insufficient)
(neighbor assist yes)

Close

No generation can be purchased, the operator then must let load shed equipment switch out load until sufficient load is off to balance the generation and remaining load.

Interruptible Load

Industrial Customers

Distribution Substation

Rule109 "Outline 1.1.1.3.2.3"
(state generation state)
(frequency low dropping)
(regulation insufficient)
(neighbor assist no)

Close

$$Reserves = \sum_{\substack{\text{all} \\ \text{on line} \\ \text{generators}}} P_{max} - \sum_{\substack{\text{all} \\ \text{on line} \\ \text{generators}}} P_{output}$$

If the generation is serving the load the only concern is whether the reserves (i.e. the sum of the on line generation capacity minus the total generation output, usually expressed as a percent of total on line capacity or a percent of load) are sufficient to meet the load if one of the operating generators failed.

+Rule110 "Outline 1.1.2"
 (state generation state)
 (on line generation capacity greater than the load)
 (on line generation output equal to the load)
 (system-data reserve min ?level)

Close

If the generation reserves are low, the operator must find more generation to bring on line. In this case the choice is to start quick start generators (e.g., hydro generators or gas turbine units) if they are available.

Normal Generator Start Up (Large Steam Unit)	==	4 -- 12 hours
Hydro Unit Start Up	==	1 minute
Combustion Turbine Start	==	1 -- 5 minutes

Rule111 "Outline 1.1.2.1.1"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve less than minimum)

Close

If enough quick start units are available the operator starts them up and brings them into synchronism with the system.

Normal Generator Start Up (Large Steam Unit) = 4 -- 12 hours

Hydro Unit Start Up = 1 minute

Combustion Turbine Start Up = 1 -- 5 minutes

Rule112 "Outline 1.1.2.1.1"
 (state generation state)
 (on line generation capacity greater than the load)
 (on line generation output equal to the load)
 (reserve less than minimum)
 (quick start yes)

Close

If insufficient quick start units are available the operator can try to purchase reserves from neighbors. This will normally cause the neighbor to start quick start units with the neighboring system unless the neighbor's reserves were in excess of the neighbor's needs.

Rule113 "Outline 1.1.2.1.2"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve less than minimum)
(quick start no)

Close

If the neighbor has
extra reserves of
extra quick start
units the purchase
of reserve
generation is made.

Interconnected Areas

Rule 1.1.4 "Outline 1.1.2.1.3"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve less than minimum)
(quick start no)
(neighbor backup yes)

Area 2

Close

If there is no quick start generation available and the

n
m
p
c

Rule115 "Outline 1.1.2.1.4"
(state generation state)
(on line generation capacity greater than the
load)
(on line generation output equal to the load)
(reserve less than minimum)
(quick start no)
(neighbor backup no)
(system-data public appeal load reduction ?load
reduction)

Close

Public appeals for load reduction will only give a small amount of load reduction, another, slightly more drastic method of load reduction, is to reduce the voltage of the substations serving the loads. The reduction in voltage will cause a further reduction in the load seen. For example, resistive loads will draw power equal to the square of voltage divided by the resistance of the load and voltage reduction will have a pronounced effect on the load drawn. Non-resistive loads, such as motors, will have a much more complex effect.

Much of the Power System's load is resistive. Lowering voltage also reduces load.

Close

Rule116 "Outline 1.1.2.1.5"

(state generation state)
 (on line generation capacity greater than the load)
 (on line generation output equal to the load)
 (reserve less than minimum)
 (quick start no)
 (neighbor backup no)
 (public appeal yes)

The last choice of the operator to reduce the margin between the available generation and the required operating reserves is to interrupt loads that have an interruptible clause in their contracts. These are usually industrial loads and the interruptible clause in the contract with the utility usually requires the utility to give a warning before cutting the load off. In this rule the availability of such load is first ascertained.

Interruptible Load

Industrial Customers

Distribution Substation

Rule117 "Outline 1.1.2.1.6"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve less than minimum)
(quick start no)
(neighbor backup no)
(public appeal yes)
(voltage reduction yes)

Close

If interruptible load is available the operator will drop enough to bring reserves back into conformity to standard operating practices. This load will be restored as soon as the overall system load drops or additional generation can be brought on line.

Rule118 "Outline 1.1.2.1.6"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve less than minimum)
(quick start no)
(neighbor backup no)
(public appeal yes)
(voltage reduction yes)
(interruptible load sufficient)

Close

The operator cannot interrupt enough load to restore frequency. All available interruptible load is shed to slow down the rate of decent of frequency. More load may have to be shed if low frequency load shed is not available.

**Interruptible
Load**

**Industrial
Customers**

Rule118A "Outline 1.1.2.1.6"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve less than minimum)
(quick start no)
(neighbor backup no)
(public appeal yes)
(voltage reduction yes)
(interruptible load insufficient)

Close

If insufficient interruptible load is available the operator has no choice other than to drop or shed load. This is allowed since there is an emergency i.e., insufficient reserves and if left alone the entire system could collapse if another generator were lost.

Interruptible Load

Industrial Customers

Rule119 "Outline 1.1.2.1.7"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve less than minimum)
(quick start no)
(neighbor backup no)
(public appeal yes)
(voltage reduction yes)
(interruptible load no)

Close

The system has enough generation on-line to meet the required load and the reserves are within normal operating ranges. However, the generation-load balance is at equality. The operator must assess the short term needs of the system by examining the load forecast for the near future. From this forecast information, the operator will determine if adjustments must be made in the generation schedule or interchange schedule. The load forecast is affected by several factors including season, weather forecast, user demand, type of load, and time of day in load cycle.

Rule120 "Outline 1.1.2.2.1"
 (state generation state)
 (on line generation capacity greater than the load)
 (on line generation output equal to the load)
 (reserve greater than minimum)

Close

The short-term load forecast was performed and the load was determined to be on a downward trend. Therefore, at this time, no adjustments are required in the generation or interchange schedule, so the operator can continue normal activities. However, if the load continues to decrease, generation and interchange schedules will have to be adjusted down to remain economical and peaking generator units may be taken off-line.

Rule121 "Outline 1.1.2.2"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve greater than minimum)
(load status load decreasing)

Close

The short-term load forecast was performed and the load demand was predicted to increase. Therefore, the operator must find enough generation to match the load. The operator must secure enough generation in the future to meet the required load. The first sources of generation are spinning reserves or off-line peak load generation units. The operator should assess if the amount of capacity available in spinning reserves or peak load units can meet the predicted short-term load forecast.

Rule122 "Outline 1.1.2.2.1.1"
 (state generation state)
 (on line generation capacity greater than the load)
 (on line generation output equal to the load)
 (reserve greater than minimum)
 (load status load increasing)

Close

The short-term load forecast is increasing and enough generation is available with spinning reserves and peak load units to meet the load. Therefore, the operator should begin the start-up procedure on the units and bring the generation on-line as the load profile increases. How long would start-up take? The operator should be in constant communication with the plant operators during the start-up and initial on-line phases. If necessary, the operator should update the AGC schedule. All switching procedures to bring the generation should be recorded and approved by the system operator.

Rule123 "Outline 1.1.2.2.1.2"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve greater than minimum)
(load status load increasing)
(generation available yes)

Close

The short-term load forecast is increasing, but the system subarea does not have enough generation available in spinning or peak load units, so the operator must look to other sources for assistance. Most utilities are members of an interconnected system or power pool from which support and assistance are available during emergency conditions. Actually, most load centers are located far from the generation plants, so power is typically transmitted over long distances involving more than one utility. When an operator has a generation deficit, the first source outside the system would be neighbors. The operator should contact the neighbor(s) or power pool operating center to request assistance. The operator should advise the neighbor(s), arrange to purchase more power, and update the interchange schedule.

Rule124 "Outline 1.1.2.2.1.3"
 (state generation state)
 (on line generation capacity greater than the load)
 (on line generation output equal to the load)
 (reserve greater than minimum)
 (load status load increasing)
 (generation available no)

Close

The operator has contacted the power pool or neighbor and advised them of the situation. The power pool or neighbor has agreed to supply generation support to the utility to meet the short-term predicted load. All transactions should be recorded by the system operator. How are prices set? Who decides where to look first? Are contracts involved covering this situation?

Rule125 "Outline 1.1.2.2.1.4"
 (state generation state)
 (on line generation capacity greater than the load)
 (on line generation output equal to the load)
 (reserve greater than minimum)
 (load status load increasing)
 (generation available no)
 (neighbor assist yes)

Close

Rule126 "Outline 1.1.2.2.1.5"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve greater than minimum)
(load status load increasing)
(generation available no)
(neighbor assist no)

Close

Rule127 "(1.1.2.2.1.6)
Generation state interruptible load 3'
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve greater than minimum)
(load status load increasing)
(generation available no)
(neighbor assist no)
(interruptible load yes)

Close

Rule128 "Outline 1.1.2.2.1.7"
(state generation state)
(on line generation capacity greater than the load)
(on line generation output equal to the load)
(reserve greater than minimum)
(load status load increasing)
(generation available no)
(neighbor assist no)
(interruptible load no)

Close

Load Resistance = R_L

$$\text{Power drawn} = \frac{(V_{BUS})^2}{R_L}$$

if $V_{BUS} \cong 1.0$ Per Unit

$$\frac{\Delta \text{Power drawn}}{\Delta V_{BUS}} \cong \frac{2 V_{BUS}}{R_L} \cong 2(\text{Original Power drawn})$$

Example : $\Delta \text{Power drawn} = 2(\text{Original Power})(\Delta V)$

if Original Power = 10 Kw

$\Delta V = 0.01$ pu

$\Delta \text{Power} = 200$ w

Voltage reduction must be studied by the utility, so the amount of load reduction vs. voltage reduction is known.

Usually voltage reduction is carried out prior to a load shed on non-interruptible

Rule129 "Outline 1.1.2.2.1.8"
 (state generation state)
 (on line generation capacity greater than the load)
 (on line generation output equal to the load)
 (reserve greater than minimum)
 (load status load increasing)
 (generation available no)
 (neighbor assist no)
 (interruptible load no)

Close

The system has entered a critical state. The load and generation are not balanced causing the frequency to drift from its normal operating point. If nothing is done, the system will enter an unstable environment, and a blackout could prevail. The on-line, spinning, and off-line generation capacity can not meet the load. The operator should contact the neighboring utility or power pool. This is an emergency situation. The operator should request emergency generation immediately to balance the load.

+Rule130 "Outline 1.2.1.1.1"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low dropping)

Close

The neighboring utility or power pool has agreed to provide emergency assistance.

The operator should arrange to receive the power into the system.

Communication should be maintained continuously during the event and the neighbor should be advised at all times of the status of the system.

The interchange schedule should be updated accordingly and all transactions recorded.

Rule131 "Outline 1.2.1.1.1"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low dropping)

(neighbor assist yes)

Close

The system has entered an emergency state.

The operator has requested support from the neighboring utilities or power pool and they could not assist.

The operator should determine if any fast-start gas-turbine units are available within the system to balance the load.

(At what point does the operator jump ahead to load shed options?

How much time is available?)

Rule132 "Outline 1.2.1.1.2"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low dropping)

(neighbor assist no)

Close

The operator has secured enough fast-start gas-turbine unit generation to raise the frequency and balance the load. The operator should order immediate start-up procedures, and maintain constant communication with the plant operator until the unit(s) are on-line and the system frequency is normal.
(How long does start-up take? Could some load shed be implemented while the operator is waiting for the units to come on-line?)

Rule133 "Outline 1.2.1.1.2"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low dropping)

(neighbor assist no)

(gas turbines available yes)

Close

The system is in an emergency state. The operator has to have more generation to balance the load. The operator has not found support from neighbors and no fast-start units are available. Next, the operator looks for more hydro generation sources. The hydro plants can be brought to full capacity in a short period of time. (How long does it take?) The generation would balance the load and return the frequency to its normal range.

Rule134 "Outline 1.2.1.1.3"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low dropping)
(neighbor assist no)
(gas turbines available no)

Close

The system operator has located hydro generation.
The operator should request immediate start-up on the hydro unit or if operating, request output to meet the required load.
How much time would elapse before the frequency was stabilized?

Trash racks
and intake

Penstock

Reservoir

Generator

Turbine

Gross
head

Draft
tube

Rule135 "Outline 1.2.1.1.3"
(state generation stat)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low dropping)
(neighbor assist no)
(gas turbines available no)
(hydro available yes)

Close

The operator is searching for generation sources to meet the load. After power pool, gas-turbine, and hydro, the operator looks to pumped storage units. (What are pumped storage units. How do they work?)

Pumped storage units are fast responding hydro generation sources that can bring generation on line quickly. If the units were pumping the system would benefit from its pumping load being dropped as well as the generation output. How long does it take to go from the pumping mode to the generation mode?

Rule 137 "Outline 1.2.1.1.4"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low dropping)
(neighbor assist no)
(gas turbines available no)
(hydro available no)
(pumped storage available yes)

Close

The frequency is decreasing due to a load-generation mismatch, and enough generation can not be secured from the system's own sources or the neighboring utility or power pool. The system must always have a balance between load and generation. If no more generation can be obtained, the system operator must reduce the load to maintain the balance. Therefore, the operator begins to examine the load reduction options available on the system.

Interruptible Load

Industrial Customers

Distribution Substation

Rule 33
(state generator no)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low dropping)
(neighbor assist no)
(gas turbines available no)
(hydro available no)
(pumped storage available no)

Subtransmission and Distribution System

Close

The system needs to reduce load to keep the load-generation balance. The operator has some customers on the system who will voluntarily allow interruption of service. These users are typically large industrial customers with some generation capacity of their own. By allowing interruption of service during peak load times, the customer has a lower rate per kWh (for they pay less). The system operator is required to give the customer notice before interruption of service to allow for conversion to other sources. At this time, the operator should give notice to the interruptible loads and prepare to discontinue service as the load profile increases.

Rule139 "Outline 1.2.1.1.5"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low dropping)

(neighbor assist no)

(gas turbines available no)

(hydro available no)

(pumped storage available no)

(interruptible load yes)

Close

Rule140 "Outline 1.2.1.1.6"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low dropping)
(neighbor assist no)
(gas turbines available no)
(hydro available no)
(pumped storage available no)
(interruptible load no)

Close

After manual or automatic load shed has been activated, the system enters a restoration

sta
pro

Close

Rule141 "Outline 1.2.1.1.7"
(load shed activated)

The system has entered a critical emergency with the potential for system collapse. Time is crucial. The operator can not consider other sources of generation to balance the load. Load shed procedures should be activated immediately. In most cases, automatic load shed will occur at a certain frequency level to maintain some system integrity. The operator should notify all neighbors and authorities of the situation, and log all events and procedures.

**Interruptible
Load**

**Industrial
Customers**

**Distribution
Substation**

Rule142 "Outline 1.2.1.2"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low emergency)

Continued

Close

After manual or automatic load shed has been activated, the system enters a
res
a n
de

Rule143 "Outline 1.2.1.2.2"
(load shed activated)

Close

The system is experiencing large flows of power on the interties between subareas of the system or neighbors.

At this point, the operator must assess the extent, size, and source of the large flow.
Are the flows within operating limits?
Do they exceed long-term overload?
Do they exceed emergency overload?

Rule144 "Outline 1.2.2.1"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low stable)
(system-data the flow max 7max)

Close

The large intertie flows have been discovered to lie within operating ranges. However, the size of the flows has attracted the operator's attention from normal experience, so the operator should continue to observe the situation for further developments. If just under the limit, the operator should investigate further the source of the large flow. Was a transmission line lost? Did something occur within the system?

Rule145 "Outline 1.2.2.1.1"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low stable)
(tie flow state within limit)

Close

Large flows on an intertie line have exceed limits.

Why would this be the neighbors problem?

The output and capacity of generation is less than the load. Wouldn't the interties be overloaded because our system was demanding more power from the neighbor to balance the load?

Rules146 "Outline 1.2.2.1.2.1"
 (state generation state)
 (on line generation capacity less than the load)
 (on line generation output less than the load)
 (frequency low stable)
 (tie flow state overloaded)

Close

The system has entered an emergency state.

The operator has requested support from the neighboring utilities or power pool and they could not assist.

The operator should determine if any fast-start gas-turbine units are available within the system to balance the load.

At what point does the operator jump ahead to load shed options?

How much time is available?

Start - up Time $\cong$ 2 min .

Fast Start
Gas Turbine

Rule147 "Outline 1.2.2.1.2.2"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low stable)

(tie flow state overloaded)

(voltage reduction yes)

Close

When frequency is low on the system, more generation needs to be placed on
line of
as fast

Start - up Time $\cong$ 2 min .

Fast Start
Gas Turbine

Close

Rule147A "Outline 1.2.2.1.2.2"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low stable)
(tie flow state overloaded)
(voltage reduction yes)
(gas turbines available yes)

The system is in an emergency state.

The operator has to have some more generation to balance the load.

The operator has not found support from neighbors and no fast-start units are available.

Next, the operator looks for some more hydro generation sources.

The hydro plants can be brought to full capacity in a short period of time.

How long does it take? The generation would balance the load and return the frequency to its normal range.

Close

If the frequency is low and hydro units are available with sufficient water in their

re
wi

Trash racks
and intake

Penstock

Reservoir

Generator

Turbine

Gross
head

Draft
tube

Close

Rule148A "Outline 1.2.2.1.2.3"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low stable)

(tie flow state overloaded)

(voltage reduction yes)

(gas turbines available no)

(hydro available yes)

The operator is searching for generation sources to meet the load.
After power pool, gas turbine, and hydro, the operator looks to pumped storage units.
What are pumped storage units?
How do they work?

Rule149 "Outline 1.2.2.1.2.4"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low stable)
(the flow state overloaded)
(voltage reduction yes)
(gas turbines available no)
(hydro available no)

Close

If the frequency is low, and pumped storage units are

Rule149A "Outline 1.2.2.1.2.4"
(state generation state)
(on line generation capacity less than the load)
(on line generation output less than the load)
(frequency low stable)
(tie flow state overloaded)
(voltage reduction yes)
(gas turbines available no)
(hydro available no)
(pumped storage available yes)

Close

The operator should update the schedule of wheeling customers.

Wheeling customers are those that send power across one power system's transmission system without supplying load in that system.

These transfers can adversely affect the loading on the system transmission lines.

Rule150 "Outline 1.2.2.1.2.5"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low stable)

(tie flow state overloaded)

(voltage reduction yes)

(gas turbines available no)

(hydro available no)

(pumped storage available no)

Close

The frequency is decreasing due to a load-generation mismatch, and enough generation can not be secured from the system's own sources or the neighboring utility or power pool.
The system must always have a balance between load and generation.
If no more generation can be obtained, the system operator must reduce the load to maintain the balance.
Therefore, the operator begins to examine the load reduction options available on the system.
Some choices of load curtailment activities include voltage reduction, voluntary interruptible_load, and load shed.

Rule151 "Outline 1.2.2.1.2.6"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low stable)

(the flow state overloaded)

(voltage reduction yes)

(gas turbines available no)

(hydro available no)

(pumped storage available no)

(wheeling customer rescheduled)

Close

Continued

**Interruptible
Load**

**Industrial
Customers**

**Distribution
Substation**

Close

The system needs to reduce load to keep the load-generation balance. The operator has some customers on the system who will voluntarily allow interruption of service. These users are typically large industrial customers

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Close

The frequency is decreasing due to a load-generation mismatch, and no generation or voluntary interruptible load is available to maintain the load-generation balance.

Hence, the operator must balance the load and generation, so the operator should begin load shed procedures.

In this case the system is critical, the frequency is decreasing and the operator has exhausted all options to balance load and generation.

Load shed should be implemented to maintain the balance and keep most load serviced.

The operator sacrifices some load service to keep the integrity of the whole system.

Rule151B "Outline 1.2.2.1.2.8"

(state generation state)

(on line generation capacity less than the load)

(on line generation output less than the load)

(frequency low stable)

(tie flow state overloaded)

(voltage reduction yes)

(gas turbines available no)

(hydro available no)

(pumped storage available no)

(wheeling customer rescheduled)

(interruptible load no)

Close

After manual or automatic load shed has been activated, the

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m
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de

Rule151C "Outline 1.2.2.1.2.9"
(load shed activated)

Close

The system has encountered a reactive power problem. The reactive power is tightly coupled to the voltage of the generator. The operator should assess the status of the reserves on the system to determine the extend of the voltage problem caused by a lack of reactive support.

Reactive Reserves: Only Generator and Capacitors
supply reactive power.

Reactive Reserves

$$= \sum_{\text{all gen}} (\text{Gen Max MVAR} - \text{Gen MVAR output}) + \sum_{\text{all caps not switched in}} \text{MVAR switched capacitors}$$

Rule152 "Outline 1.3.1"
(state generation state)
(voltage low)
(system-data var reserve min ?min)

Close

One of the sources of reactive power is a switchable capacitor. A capacitor brings leading reactive power on to the system to balance the lagging reactive power of most loads. The capacitor works to correct the power factor and improve system performance.

Rule153 "Outline 1.3.1.1.1"
(state generation state)
(voltage low)
(reserve less than minimum)

Continued

Close

The system has encountered some reactive power problem. The reactive power supply and generator voltage are tightly coupled. The reactive power problem has developed, but, at this point the voltage is still within range. The operator should examine the amount of reactive reserves available to supply support in the near future.

Continued

Close

Reactive Reserves:

**Only Generators and Capacitors
supply reactive power.**

$$\begin{aligned} \text{Reactive Reserves} = & \sum_{\text{all gen}} (\text{Gen Max MVAR} - \text{Gen MVAR output}) \\ & + \sum_{\text{all caps not switched in}} \text{MVAR switched capacitors} \end{aligned}$$

Close

If frequency is decreasing slowly, the operator can correct the problem by changing parameters of the automatic generation control (AGC) system.

Automatic Generation Control (AGC) system

More

Close

Voltage Reduction is used to reduce loads which are primarily resistive (lamps, heaters, etc. . .)

V_{BUS}

$$\text{Load Resistance} = R_L$$

$$\text{Power drawn} = \frac{(V_{BUS})^2}{R_L}$$

$$\text{if } V_{BUS} \cong 1.0 \text{ Per Unit}$$

$$\frac{\Delta \text{Power drawn}}{\Delta V_{BUS}} \cong \frac{2 V_{BUS}}{R_L} \cong 2(\text{Original Power drawn})$$

$$\text{Example : } \Delta \text{Power drawn} = 2(\text{Original Power})(\Delta V)$$

$$\text{if Original Power} = 10 \text{ Kw}$$

$$\Delta V = 0.01 \text{ pu}$$

$$\Delta \text{Power} = 200 \text{ w}$$

Close

The voltage of the system has dipped and the reserves available are insufficient to raise the voltage. The operator has located a capacitor bank to provide support and raise the voltage. The operator should arrange to switch the capacitor on-line.

Reactive Reserves: Only Generator and Capacitor
supply reactive power.

Reactive Reserves = $\sum_{\text{all gen}} (\text{Gen Max MVAR} - \text{Gen MVAR output})$
+ $\sum_{\text{all caps not switched in}} \text{MVAR switched capacitors}$

Rule154 "Outline 1.3.1.1.2"
(state generation state)
(voltage low)
(reserve less than minimum)
(switchable capacitor available yes)

Close

The operator has no capacitors available to provide reactive balance. Therefore, other options should be investigated. Depending the severity of the voltage dip, the operator could back off MW's to increase VAR output. How does this work? What are its limitations?

Rule155 "Outline 1.3.1.1.3"
 (state generation state)
 (voltage low)
 (reserve less than minimum)
 (switchable capacitor available no)

Close

Determining load shed vs. reactive problem correction requires a series of AC power flows.

Remove load to restore

Reactive Balance.

(Note : Load removal gains the benefit of

Q_{loss} reduction in the transmission lines .)

Close

After manual or automatic load shed has been activated, the system enters a restoration state. Here, the system state is mapped from a generation problem to a restoration problem, where the event leading to a loss of service was frequency deviation.

Rule157 "Outline 1.3.1.1.8"
(load shed activated)

Close

The voltage on the system has
dipped. The system has enough
spinning reactive reserves to raise
the voltage back to the normal
operating range.

Rule158 "Outline 1.3.1.2"

(state generation state)

(voltage low)

(reserve greater than minimum)

Close

One of the sources of reactive power is a switchable capacitor. A capacitor brings leading reactive power on to the system to balance the lagging reactive power of most loads. The capacitor works to correct the power factor and improve system performance.

Rule160 "Outline 1.3.2.1.1"
(state generation state)
(voltage within limit)
(reserve less than minimum)

Continued

Close

The voltage of the system has dipped and the reserves available are insufficient to raise the voltage. The operator has located a capacitor bank to provide support and raise the voltage. The operator should arrange to switch the capacitor on-line.

Reactive Reserves:

+Rule161 "Outline 1.3.2.1.2"
(state generation state)
(voltage within limit)
(reserve less than minimum)
(switchable capacitor available yes)

$$= \sum_{\text{all gen}} (\text{Gen Max MVAR} - \text{Gen MVAR output}) + \sum_{\text{all caps not switched in}} \text{MVAR switched capacitors}$$

Reactive Reserves:

Only Generator and Capacitors supply reactive power.

Close

The operator has no capacitors available to provide reactive balance. Therefore, other options should be investigated. Depending the severity of the voltage dip, the operator could back off MW's to increase VAR output.

Rule162 "Outline 1.3.2.1.3"
 (state generation state)
 (voltage within limit)
 (reserve less than minimum)
 (switchable capacitor available no)

Close

Reserves greater than
minimum are of little concern
except in so far as they may
be costing the utility to carry
them.

Close

The frequency is decreasing due to a load-generation mismatch, and no generation or voluntary interruptible load is available to maintain the load-generation balance. Hence, the operator must balance the load and generation, so the operator should begin load shed procedures. In this case the system is critical, the frequency is decreasing and the operator has exhausted all options to balance load and generation. Load shed should be implemented to maintain the balance and keep most load serviced. The operator sacrifices some load service to keep the integrity of the whole system.

The short-term load forecast is increasing and no generation or voluntary interruptible load is available to maintain the load-generation balance.

Hence, the operator must balance the load and generation, so the operator should prepare to begin load shed procedures.

In this case the system is not critical at the present moment, but the load demand is increasing and the operator has exhausted all options to balance load and generation.

Load shed should be implemented to maintain the balance and keep most load serviced.

The operator sacrifices some load service to keep the integrity of the whole system.

Rule

Close

The system needs to reduce load to keep the load-generation balance. The operator has some customers on the system who will voluntarily allow interruption of service. These users are typically large industrial customers with some generation capacity of their own. By allowing interruption of service during peak load times, the customer has a lower rate per kWh (i.e. they pay less). The system operator is required to give the customer notice before interruption of service to allow for conversion to other sources. At this time, the operator should give notice to the interruptible loads and prepare to discontinue service as the load profile increases.

Rule

Close

The short-term load forecast shows increasing load, and enough generation can not be secured from the system's own sources or the neighboring utility or power pool.

The system must always have a balance between load and generation.

If no more generation can be obtained, the system operator must reduce the load to maintain the balance.

Therefore, the operator begins to examine the load reduction options available on the system.

Some choices of load curtailment activities include voltage reduction, voluntary interruptible load, and load shed.

Rule

Close

Appendix B

Transmission Event Graphics

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+ Rule218 "(2.1.2.3.3) (Transmission state interior overload on contingency action3" (state transmission state) (initial result overload) (location interior) (next contingency yes) (next contingency severe yes) (generation shifting no)	+Rule221 "Outline 2.1.2.3.6" (state transmission state) (initial result overload) (location interior) (next contingency yes) (next contingency severe yes) (generation shifting no) (corrective switching no) (wheeling customer yes)	+ Rule225 "Outline 2.2.3.2" (state transmission state) (initial result voltage limit violation) (voltage changing)
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+ Rule229 "Outline 2.1.4.1.1.1" (state transmission state) (initial result system islanded) (islanded all load serviced) (frequency stable in each island) (voltage within limit)	+ Rule233 "Outline 2.1.4.2.1" (state transmission state) (initial result system islanded) (islanded blacked out) (frequency stable)	+(Rule236 "Outline " (state transmission state) (initial result load lost) (load lost large) (system-data num service connects ?num)
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+ Rule244 (state transmission state) (initial result voltage limit violation on contingency)	
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TRANSMISSION SYSTEM INITIAL EVENTS"

1. Breaker Lockout"
2. Breaker Misoperation"
3. Breaker Trip"
4. Capacitor/Reactor Switching"
5. Fault - Single Phase"
6. Fault - Multiple Phase"
7. Open Both Ends of Line"
8. Open Both Ends of Transformer"
9. Open One End of Line"
10. Open One End of Transformer"
11. Continue to Next Menu"

Close

TRANSMISSION SYSTEM INITIAL EVENTS"

11. Overloaded Line"
12. Overloaded Transformer"
13. Overtemperature on Transformer"
14. Split Bus"
15. System Split - Islanding"
16. Voltage Low on a Bus"
17. Var Reserves Low"
18. Overloaded Tie Line"
19. Load Lost"
20. Transient Fault"
21. Switching"
22. Overload On Next Contingency"
23. Voltage Problem On Next Contingency"
24. Exit to Main Menu"

Close

The transmission system is the medium of getting power delivered from the power plants to the distribution system and then to customers. The transmission system can suffer faults (short circuits to ground or between phases) which result in breaker openings and the opening of transmission lines or transformers. In addition, the switching of capacitors and transformer taps must be done to keep voltages in the transmission system within bounds. Transmission line and transformers can be overloaded causing over temperatures. When breakers are opened, the buses can be split, or lines and transformers can be opened at one or both ends resulting in lost load or a split system.

tran1 menu
(tran evt menu display)

Close

The initial event selected by the user was a breaker lockout. After a breaker has locked out, it is impossible for the operator to reclose on the line or transformer. It must be determined exactly what caused the lockout. Was auto-reclose or manual reclose tried? If reclose was attempted, how many times? Does it appear to be a failure?

Rule11 "Transmission event breaker lockout"
(event breaker lockout)

Close

The initial event selected by the user was a circuit breaker failure. As discussed in the explanation, the breaker can fail in two ways. The operator must establish which situation has occurred. Has any equipment been effected? Are all loads serviced? The operator should maintain service to all loads while isolating the problem. After the cause of the failure has been identified, the operator should schedule maintenance repair or replacement on the unit.

Rule12 "Event breaker misoperation"
(event breaker misoperation)

Close

The initial event selected by the user was a breaker trip. Initially, the operator would examine why the breaker tripped. Moreover, once a breaker has tripped, the system can be left in several conditions. The operator must know what components are effected by the operation of the breaker. This knowledge base gives the user four selections. These subsequent results are brought to a state where further system effects are analyzed.

Rule13 "Event breaker trip"
(event breaker trip)

Close

The initial event selected by the user was a capacitor or reactor switching. Generally, these actions are done in an attempt to correct a voltage problem on the system. Is this a response to any earlier problem? The voltage problem is tightly coupled to the reactive power of the generation units. Has this switching been done to correct a reactive power deficit? Once the capacitor or reactor switching has been done, the operator must identify the status the of the system voltage. Here, the voltage can be too low, too high, or within specified limits. If the switching action did not correct the problem, then the operator must proceed with other options. What if voltage is still too high? What if voltage is still too low?

Rule14 "Event capacitor reactor switching"
(event capacitor reactor switching)
(system-data voltage min2 ?min)
(system-data voltage max ?max)

Close

The initial event selected by the user was a single phase fault. When a fault occurs on the power system, a circuit breaker trips to remove the fault. Did the breaker function properly? Was the primary protection system operating properly? Was any backup required? Since a breaker has tripped on a single phase, several components could have been effected. Listed are some options for equipment effected by a single breaker action. These secondary events lead to states of the power system for further assessment by the operator.

Close

Rule15 "Transmission event fault single phase"
(event fault single phase)

The initial event selected by the user was a poly phase fault. When a poly-phase fault occurs on the power system, one or more circuit breakers activated to remove the faulted phases. Did the breakers function properly? Was primary protection operating properly? Was any backup system functions required? A poly-phase fault generates large current flows on the power system. Did any component damage occur? Did flashover occur? Additionally, after the fault has been removed, the operator must be concerned with the present state of the system and any transient effects felt by the breaker action.

Rule16 "Transmission event fault multiple
phase"
(event fault multiple phase)

Close

The initial event selected by the user was open both ends of a transmission line. If both ends of a line are opened, obviously the power flow on the line is zero. Both ends of the line could have been opened by a fault or maintenance. Nevertheless, the system operator should be concerned with the remaining system. What effects did the loss of this line have on the other parts of the network. Is there an overload? Does the system have a voltage problem? Are all loads still serviced? Did the system become islanded?

Rule18 "Transmission event open both ends
of a line"
(event open both ends of a line)

Close

The initial event selected by the user was open both ends of a transformer. The transformer has been removed from service. The operator should be interested in the effects on the remaining system. Is there an overload? Does the system have a voltage problem? Are all loads still serviced? Did the system become islanded? Was the loss of this transformer scheduled maintenance or unscheduled? What is the integrity of remaining system? How critical is the return of this transformer to service?

Rule19 "Transmission event open both ends of a transformer"
(event open both ends of a transformer)

Close

The initial event selected by the user was open one end of a transmission line. If both ends of a line are opened, obviously the power flow on the line is zero. Both ends of the line could have been opened by a fault or maintenance. Nevertheless, the system operator should be concerned with the remaining system. What effects did the loss of this line have on the other parts of the network. Is there an overload? Does the system have a voltage problem? Are all loads still serviced? Did the system become islanded?

Rule20B "Transmission event open one end of a
line"
(event open one end of a line)
(reclosure of line unsuccessful)

Close

The initial event selected by the user was open one end of a transformer. The transformer has been removed from service. This does not mean the transformer is not electrically isolated, but the power flowing through the transformer is equal to zero. The operator should be interested in the effects on the remaining system. Is there an overload? Does the system have a voltage problem? Are all loads still serviced? Did the system become islanded? Was the loss of this transformer scheduled maintenance or unscheduled? What is the integrity of remaining system? How critical is the return of this transformer to service?

Rule21B "Transmission event open one end of a transformer"
(event open one end of a transformer)
(reclosure of transformer unsuccessful)

Close

The transmission system is the medium of getting power delivered from the power plants to the distribution system and then to customers. The transmission system can suffer faults (short circuits to ground or between phases) which result in breaker openings and the opening of transmission lines or transformers. In addition, the switching of capacitors and transformer taps must be done to keep voltages in the transmission system within bounds. Transmission line and transformers can be overloaded causing over temperatures. When breakers are opened, the buses can be split, or lines and transformers can be opened at one or both ends resulting in lost load or a split system.

tran2 menu
(trn evt2 menu display)

Close

Some load service has been lost. Continuity of service is a high priority of all utilities. The operator must quickly determine what has caused the outage, how to restore power to those customers, and when to do required repairs. After initial notification that load has been lost, the operator should determine how wide spread the outage is. Therefore, the first question is how many substations are involved. Is it an isolated problem? How many feeders? Which transmission lines? Has generation been lost?

Rule17 "Transmission event load lost"
(event load lost)

Close

The initial event selected by the user was an overloaded intertie line. With the complexity of highly interconnected power systems and the frequent buying and selling of power, the intertie lines between utilities have become critical components of power system reliability and security. As a result, the intertie lines are monitored closely for limit violations. When an overload is detected on a line, the operator should quickly analyze the situation for possible damage to the transmission lines. Neighboring utilities should be contacted to assist with the identification of the problem.

Rule22 "Transmission event overloaded tieline"
(event overloaded tie line)

Close

The initial event selected by the user was an overloaded line within the utility and not an intertie line. This case is confined to the realm of the operators own system. First, the operator should examine the system for possible damage to components. Next, steps should be outlined to remove the overload. Is the overload within short term limits? Is the overload a emergency? How long can this overload be sustained on the system without damage?

**Rule23 "Transmission event overload line"
(event overloaded line)**

Close

The initial event selected by the user was an overloaded transformer. The operator should assess the size of the overload. Has the overload reached a critical limit? Generally, transformers have cooling equipment attached, so the overloads are not as critical as with transmission lines. Why is the transformer overloaded? Did another transformer fail? What has the transformer performance reports recorded?

Rule24 "Transmission event overloaded
transformer"
(event overloaded transformer)

Close

The initial event selected by the user was a split bus. A split bus occurs from the operation of a circuit breaker. (Was the splitting of this bus for maintenance or unscheduled?) The actual splitting of the bus leads to a less secure operating condition. For example, if one other component breaker fails, then the whole bus may be lost. Hence, the operator is concerned with the present condition after the bus is split. Is an overload occurring? Is the voltage low? Has any load been lost? Are parts of the system islanded?

Rule25 "Transmission event split bus"
(event split bus)

Close

The initial event selected by the user was system split or system islanding. If the system has islanded, then the power system is in a degraded operating state. The operator must determine the amount of service intact in each island. If all loads are serviced, then the parts just need to be synchronized and re-connected. However, if load has been partially or totally lost, then the operator enters the system into a restorative state to re-establish service.

Rule26 "Transmission event system split
islanding"
(event system split islanding)

Close

The initial event selected by the user was var reserves are low. The vars of the system are a reactive power problem. The reactive power of the system is tightly coupled to the voltage magnitude. This problem can be addressed through generation and transmission. The operator must examine the voltage because this quantity indicates the correction levels.

Rule28 "Transmission event var reserves low"
(event var reserves low)

Close

The initial event selected by the user was voltage low on a bus. The reactive power of the system is tightly coupled to the voltage magnitude. This problem can be addressed through generation and transmission. The operator must examine the voltage because this quantity indicates the correction levels.

Rule29 "Transmission event voltage low on bus"
(event voltage low on bus)

Close

A transient fault will be in effect for a short period but can cause the generators to have synchronization problems and can result in damage. Usually, relay systems are designed to remove faults quickly enough to prevent transient problems from becoming serious.

**Rule30 "Transmission event transient
fault"
(event transient fault)**

Close

Switching may or may not result in a problem on a system. if the switching is under the control of the operator there is good reason to believe the actions are being monitored.

Rule31 "Transmission event switching"
(event switching)

Close

An overload on contingency means that the indicated outage shown by the security analysis program will result in an overload. The response to this depends on the magnitude of the contingency overload.

**Rule32 "Transmission event overload on
contingency"
(event overload on contingency)**

Close

An overload on contingency means that the indicated outage shown by the security analysis program will result in an overload. The response to this depends on the magnitude of the contingency overload.

**Rule32A "Overload on contingency caused by
other event."
(Initial result overload on contingency)**

Close

A voltage problem on contingency means that the indicated outage shown by the security analysis program will result in a voltage limit violation.

**Rule32B "Voltage violation on contingency caused
by other event"
(event voltage limit violation on contingency)**

Close

The cause for the overloaded intertie line has been determined to lie outside the operator's utility. The implication is the neighbor has a generation deficit and can not meet the required load. Through communication conversations, it is discovered if the other utility has enough generation on-line, spinning reserve, fast-start, or capacity to meet the load. If yes, the neighboring utility should raise generation to meet the load and reserve margin, so as to eliminate the overloaded intertie. If no, other interties must be used to supply generation from remote locations. The operator of this utility should assist on an economic dispatch basis if possible. In emergency situations, the operator must maintain the integrity of his system, so if a severe intertie overload occurs with the deficit on the outside, the operator may have to open the intertie lines to keep the system secure. This would be a last resort, desperate action and would effectively throw the neighboring utility into crippled state.

Rule202 "Outline 2.1.1.2.1"
(state transmission state)
(initial result overload)
(location tie line)
(direction plus)

Close

With all load serviced and voltage low, it is important to get the voltage back to normal. Since it is islanded the operator will not be able to re-establish voltage by any other means than load shedding.

Rule230 "Outline 2.1.4.1.2"
(state transmission state)
(Initial result system islanded)
(Islanded all load serviced)
(frequency stable in each island)
(voltage low)

Close

When a system is islanded it is very important to maintain control over generation and load balance in each island. If one of the islands is connected to neighboring system this island will be easier to control. If load is lost in an isolated island, there is need to control the island frequency beofre load can be restored.

Rule234A "Outline 2.1.4.2.2"
(state transmission state)
(Initial result system islanded)
(Islanded partial loss of load)

Close

The system components or operator have initiated some switching actions on the power system. The effects of the action on the state of the system is quite important. The operator should investigate any problems resulting from the switching action.

Rule243 "Outline 2.4"
(state transmission state)
(initial result switching)

Close

The overloaded line has been located inside the operator's utility and has been classified as severe. As a severe overload, the time frame of actions is quite short. If the overload is not reduced quickly, then the possibility of damage and permanent loss of equipment raises rapidly. With a severe overload, the system has lost some transmission equipment, so the other lines have picked up the load to retain service. This load throw-over has caused an overload on a line. With the loss of some equipment, the operator's options to relieve the overload are reduced. Therefore, the operator should immediate run a corrective action study to reduce the overload. If the overload load persists, eventually protection equipment will operate to remove the overload an in the process service continuity to some loads will be lost. With this severe interior overload the operator wants immediate action, so the first step is analysis of generation shifting. The overload implies imbalances between load and generation at different portions of the system, so generation shifting means that the power is generated close to the load center. What is MW caused? What is transformer MVA? What are circulating VARS? Can we establish which one? If so, how?

Rule207B "Outline 2.1.2.1.1"
(state transmission state)
(Initial result overload)
(location interior)
(long term limit yes)

Continued

Close

The line overload can be

MW Flow
(Overload)

Decrease
MW
Generated

MW Flow
(Reduced)

Increase
MW
Generated

Using Generator Shifting to
Relieve Overloads

Close

+ Rule209 "Outline 2.1.2.2.2"
(state transmission state)
(initial result overload)
(location interior)
(long term limit yes)
(generation shifting yes)

The overloaded line on next contingency has been located inside the operator's utility and has been classified as severe. As a severe overload, the time frame of actions is quite short. If the overload is not reduced speedily, then the possibility of damage and permanent loss of equipment raises rapidly. With a severe overload, the system has lost some transmission equipment, so the other lines have picked up the load to retain service. This load throw-over has caused an overload on a line. With the loss of some equipment, the operator's options to relieve the overload are reduced. Therefore, the operator should immediately run a corrective action study to determine how to reduce the overload. If the overload load persists, eventually protection equipment will operate to remove the overload and in the process service continuity to some loads will be lost. With this severe interior overload the operator wants immediate action, so the first step is analysis of generation shifting. The overload implies imbalances between load and generation at different portions of the system, so generation shifting means that the power is generated close to the load center. What is MW caused? What is transformer MVA? What are circulating VARS? Can we establish which one? If so, how?

+Rule216 "Outline 2.1.2.3.1"
(state transmission state)
(initial result overload)
(location interior)
(next contingency yes)
(next contingency severe yes)

Continued

Close

+Rule217 "Outline 2.1.2.3.2"
(state transmission state)
(initial result overload)
(location interior)
(next contingency yes)
(next contingency severe yes)
(generation shifting yes)

Close

Why would we shift generation

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Lower Voltage
Circuits

Opening Lower
Voltage Circuits
will relieve overload

+Rule210 "Outline 2.1.2.2.3"
(state transmission state)
(initial result overload)
(location interior)
(long term limit yes)
(generation shifting no)

Close

The operator has determined that corrective switching

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c

Lower Voltage
Circuits

Opening Lower
Voltage Circuits
will relieve overload

+Rule211 "(2.1.2.2.4) Transmission state
interior overload action3"
(state transmission state)
(initial result overload)
(location interior)
(long term limit yes)
(generation shifting no)
(corrective switching yes)

Close

The operator has determined that corrective switching can eliminate the severe internal overload. Corrective switching may alter the flow pattern through the system and may require that the overloaded line be dropped. At this point, no severe interruption should occur. Other options will be investigated first. It is obvious that at any point an overload can be removed by opening a line; however, the ramifications of this action are important. The operator does not want to escalate the problem.

+ Rule219 "Outline 2.1.2.3.4"
 (state transmission state)
 (initial result overload)
 (location interior)
 (next contingency yes)
 (next contingency severe yes)
 (generation shifting no)
 (corrective switching yes)

Close

The severe internal overload continues. The operator has tried generation shifting and corrective switching, but both have failed to eliminate the overload. Next the operator should identify any wheeling customer on the overloaded line. Remember, the operator remains loyal to the integrity of his system, so if dropping a wheeling customer is necessary to keep service continuity, then it must be done.

+Rule212 "Outline 2.1.2.2.5"
(state transmission state)
(initial result overload)
(location interior)
(long term limit yes)
(generation shifting no)
(corrective switching no)

Close

The operator has tried other methods to relieve the severe overload, but all have failed. At this point, the operator needs to drop any wheeling customers on the overloaded transmission lines. The operator should contact the wheeling customer to notify them and give an indication of when wheeling service can be restored.

+Rule213 "Outline 2.1.2.2.6"
(state transmission state)
(initial result overload)
(location interior)
(long term limit yes)
(generation shifting no)
(corrective switching no)
(wheeling customer yes)

Close

~~The severe internal overload on next contingency continues. The operator has tried generation shifting and corrective switching, but both have failed to eliminate the overload. Next, the operator should identify any wheeling customer on the overloaded line. Remember, the operator remains loyal to the integrity of his system, so if dropping a wheeling customer is necessary to keep service continuity, than it must be done.~~

+Rule220 "Outline 2.1.2.3.5"
(state transmslssion state)
(initial result overload)
(location interior)
(next contingency yes)
(next contingency severe yes)
(generation shifting no)
(corrective switching no)

Close

The operator has tried other

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Seller

Buyer

Large Wheeling
Flow

Close

+Rule221 "Outline 2.1.2.3.6"
(state transmission state)
(initial result overload)
(location interior)
(next contingency yes)
(next contingency severe yes)
(generation shifting no)
(corrective switching no)
(wheeling customer yes)

Phase angle detction relay will prevent reclose if beyond limit.

+Rule20 "Transmission event open one end of a
transmission line"
(event open one end of a line)

Transient Fault Cleared and Breakers
Reclosed

Close

If a transmission line was opened and reclosed, the operator needs to monitor the situation to be sure the problem has gone away.

Pre Fault

Fault Strikes

**Breakers Open
Fault Clears**

**Breakers Reclose
Automatically**

Transient Fault Cleared and Breakers Reclosed

Close

+Rule20A "Transmission event open one end of a line"
(event open one end of a line)
(reclosure of line successful)

If the transformer has been opened and reclosed successfully the situation must be monitored to be sure the problem has cleared.

Pre Fault

Fault Strikes

Breakers Open
Fault Clears

Breakers Reclose
Automatically

Transient Fault Cleared and
Breakers Closed

Close

+Rule21 "Transmission event open one end of a transformer"
(event open one end of a transformer)

If the transformer has been opened and reclosed successfully the situation must be monitored to be sure the problem has cleared.

Pre Fault

Fault Strikes

**Breakers Open
Fault Clears**

**Breakers Reclose
Automatically**

**Transient Fault Cleared and
Breakers Closed**

Close

+Rule21A "Transmission event open one end of a transformer"
(event open one end of a transformer)
(reclosure of transformer successful)

An overload has been detected on the transmission system. The first step determines if the overload is located on an intertie line or interior line. The answer immediately defines the scope of the problem. Does the operator need to contact interact with a neighboring utility? The method of reducing the largest overload first allows the system to remove/create other minor overloads to eliminate the major problems on the network. The power flow studies switching options to address the most critical overloads first. From the power flow results, the operator can review secondary effects and analyze the 'best' sequences of switching operations to diminish the overloaded state of the transmission line.

+ Rule200 "Outline 2.1.1"
(state transmission state)
(initial result overload)

Close

+Rule207 "Outline 2.1.2.1"
(state transmission state)
(initial result overload)
(location interior)

Line Rating	Long Term Overload	Short Term Overload
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—————> Loading of Transmission Line

Long Term Overload • Overload can exist for several hours with damage to line.

Short Term Overload • Overload must be relieved quickly to prevent damage

The overload has been located inside the operator's system and the severity has been classified as minor. As a minor overload, the operator is not concerned with damage to equipment, loss of a line, or loss of generation. The time frame of action can be quite relaxed. The operator should run a power flow to observe if the overload disappears naturally. This would indicate a temporary system state resulting from some natural variance in loading conditions. However, if the overload persists, the operator should run a corrective action study to establish switching options to eliminate the overload. Also, in this case, the overload could move from minor status to severe status on a next contingency. What is a power flow and what does it tell the operator? What is a corrective action study? For determination of the importance of the overload, the operator should compare the current overload to the limits and specifications of the lines.

Close

The overload has been established as a minor interior overload that does not exceed the long term overload limit. What is this limit? Are there short-term and emergency limits? The operator should monitor the situation closely for any changes in the overload, but at this time no further action is required. The operator should record this occurrence for future references or trends in the load profile.

Line Rating	Long Term Overload	Short Term Overload

→ Loading of Transmission Line

Long Term Overload • Overload can exist for several hours with damage to line.

Short Term Overload • Overload must be relieved quickly to prevent damage

Close

+ Rule207A "Outline 2.1.2.1.1"
(state transmission state)
(initial result overload)
(location interior)
(long term limit no)

The initial event selected by the user was a circuit breaker failure. As discussed in the explanation, the breaker can fail in two ways. The operator must establish which situation has occurred. Has any equipment been effected? Are all loads serviced? The operator should maintain service to all loads while isolating the problem. After the cause of the failure has been identified, the operator should schedule maintenance repair or replacement on the unit.

+ Rule242 "Outline 2.3"
(state transmission state)
(breaker failure yes)

**High Current interruption requires
Oil or Air blast to extinguish
Arcing Contacts of Power
Circuit Breakers.**

Close

The overloaded line has been identified as an intertie with a neighboring utility. The operator should establish contact by phone immediately while the location and severity of the overload are being assessed. The imbalance in real power defines the severity of the overload and the location is established by the difference between scheduled and actual interchange. If the disturbance is inside the operator's own utility, then the operator must determine the source/cause of the overload and begin outlining options. If the disturbance is outside, in the neighboring utility, then the operator should request a status report from the neighboring utility operator and begin outlining contingency plans.

Δ = Scheduled Net Interchange (MW) - Actual Net Interchange (MW)

if Δ positive → load lost in internal area or generator lost
in external area .

Δ negative → generator lost in internal area or load lost
in external area .

+Rule201 "Outline 2.1.1.2"
(state transmission state)
(initial result overload)
(location tie line)

Close

The cause of the overloaded intertie line has been determined to lie inside the operator's system. The overloaded line has evolved from a deficit of generation in this system. The operator should determine why the load and generation are not balanced. Close communication with the neighboring utility is desired at all times. The relative severity of the overload should be established immediately. The severity is a key factor in determining what actions should be taken and how quickly actions are required. Status reports should be given often depending on the severity of the situation. What is severe? What is minor?

Δ = Scheduled Net Interchange (MW) – Actual Net Interchange (MW)

if Δ positive → load lost in internal area or generator lost
in external area .

Δ negative → generator lost in internal area or load lost
in external area .

+Rule203 "Outline 2.1.1.2.2"
(state transmission state)
(initial result overload)
(location tie line)
(direction minus)

Close

The overload has been located inside the operator's system and the severity has been classified as minor. As a minor

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Δ = Scheduled Net Interchange (MW) – Actual Net Interchange (MW)

if Δ positive → load lost in internal area or generator lost
in external area .

Δ negative → generator lost in internal area or load lost
in external area .

+Rule204 "Outline 2.1.1.3"
(state transmission state)
(initial result overload)
(location tie line)
(intensity minor)

Close

The overloaded line has been located inside the operator's utility and has been classified as severe. As a severe overload,

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Δ = Scheduled Net Interchange (MW) – Actual Net Interchange (MW)

if Δ positive → load lost in internal area or generator lost
in external area .

Δ negative → generator lost in internal area or load lost
in external area .

+Rule205 "Outline 2.1.1.4"
(state transmission state)
(initial result overload)
(location tie line)
(intensity severe)

Close

The operator has exhausted all options to remove the severe internal overload. At this time, the operator should begin manual load shedding in specified areas to relieve the overloaded line. The imbalance of load and generation should be located in a certain segment of the system, so the operator should selectively drop load to minimize the interruptions of service.

Drop Generators

Drop Load

**Load Shedding relieves large
flow in vicinity of load.**

Close

+Rule214 "Outline 2.1.2.2.6"
(state transmission state)
(initial result overload)
(location interior)
(long term limit yes)
(generation shifting no)
(corrective switching no)
(wheeling customer no)

The operator has exhausted all options to

Drop Generators

Drop Load

**Load Shedding relieves large
flow in vicinity of load.**

+Rule222 "Outline 2.1.2.3.7"
(state transmission state)
(initial result overload)
(location interior)
(next contingency yes)
(next contingency severe yes)
(generation shifting no)
(corrective switching no)
(wheeling customer no)

Close

The system has a bus voltage problem.

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**Voltage
Level**

+ Rule223 "Outline 2.1.3"
(state transmission state)
(initial result voltage limit violation)

Close

The system has a bus voltage

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Voltage
Level

Upper Limit

Lower Limit

Corrective
Action

In Violation

Voltage Violation
but constant

Time

Close

+ Rule224 "Outline 2.1.3.1"
(state transmission state)
(initial result voltage limit violation)
(voltage constant)

The system has entered an emergency

Voltage
Level

Upper Limit

Lower Limit

In Violation

If Voltage is decreasing
drop load

Time →

Close

+ Rule225 "Outline 2.2.3.2"
(state transmission state)
(initial result voltage limit violation)
(voltage changing)

The system has entered an islanded state. How did it get here? The operator should immediately establish what loads

a
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o

**An Island is formed when all
lines into a section of the system
are opened.**

+ Rule226 "Outline 2.1.4"
(state transmission state)
(initial result system islanded)

Close

The operator begins assessing the

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+Rule227 "Outline 2.1.4.1"
(state transmission state)
(initial result system islanded)
(islanded all load serviced)

Close

The system has islanded and loads

Close

The remainder of the system is still struggling to

+Rule234 "Outline 2.1.4.2.2"
(state transmission state)
(initial result system islanded)
(islanded blacked out)
(frequency varying)

The remaining portions of the system are stable and within normal operating constraints. The operator should
in

+ Rule233 "Outline 2.1.4.2.1"
(state transmission state)
(initial result system islanded)
(islanded blacked out)
(frequency stable)

Close

In the islanded state with all loads serviced,

after
load
voltage
stable
voltage
stable
before
before
attain

+ Rule228 "Outline 2.1.4.1.1"
(state transmission state)
(initial result system islanded)
(islanded all load serviced)
(frequency stable in each island)
(system-data voltage min2 ?min)
(system-data voltage max ?max)

Voltage

The system is functioning as individual island with all loads Voltage

+ Rule229 "Outline 2.1.4.1.1.1"
(state transmission state)
(initial result system islanded)
(islanded all load serviced)
(frequency stable in each island)
(voltage within limit)

The power system has islanded and some islands have blackout conditions. The
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+Rule232 "Outline 2.1.4.2"
(state transmission state)
(Initial result system islanded)
(Islanded blacked out)

Close

The system has a blackout condition.

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+Rule240 "Outline 2.1.6"
(state transmission state)
(initial result load lost)
(load lost blackout)

Close

A disturbance within the system has caused the loss of load service. The operator should assess the extent of the large

+ Rule235 "Outline 2.1.5"
(state transmission state)
(initial result load lost)
(system-data load lost scale
?threshold)

Close

The operator has determined that a large amount of load has been lost. The operator begins tracing the

so
of
pr

Substation

Sub B

Sub A

Sub C

+(Rule236 "Outline "
(state transmission state)
(initial result load lost)
(load lost large)
(system-data num service connects ?num)

Close

The power system has a large load loss involving one substation. The operator must find the

+Rule239 "Outline 2.1.5.1"
(state transmission state)
(initial result load lost)
(load lost large)
(substation one)

Close

The power system has a large load loss involving several substations. The operator must find the source of the outage. Possibilities include generation and transmission components. Would this occur without warning? What previous states would exist? Does this indicate an obvious major problem in generation or transmission?

+ Rule238 "Outline 2.1.5.2.1"
(state transmission state)
(initial result load lost)
(load lost large)
(substation several)

Close

The next contingency overload, if severe (i.e., > short term rating) must be dealt with, else, it simply must be watched.

Pre Contingency

Possible Post Contingency Flows

+Rule215 "Outline 2.1.2.3"
(state transmission state)
(initial result overload)
(location interior)
(next contingency yes)

Close

Monitor situation is the only action here.

Pre Contingency

**Possible Post
Contingency Flows**

+ Rule215A
(state transmission state)
(initial result overload)
(location interior)
(next contingency yes)
(next contingency severe no)

Close

Overtemp can be caused by several

+Rule33 "Transmission event overtemp on transformer"
(event overtemperature on transformer)

Close

Close

What is the purpose of the

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th
re
co
sy
co
pr

Pre Fault

**Fault
Strikes**

**Breakers
Open
Fault
Clears**

**Breakers
Reclose
Automatically**

**Transient Fault Cleared and Breakers
Reclosed**

Close

+Rule241 "Outline 2.2"
(state transmission state)
(transient fault removed)

The operator has determined that a small amount of load has been lost. The operator begins tracing the source of the problem. Did a bus fault occur? Did protection equipment fail? If reclose is suggested, does small mean single line, feeder, or single substation? What are we reclosing on? If the problem requires repair, do we send a crew? How fast should the work be done?

+Rule237 "2.1.5.3"
(state transmission state)
(initial result load lost)
(load lost small)

Close

**Lower Voltage
Circuits**

**Opening Lower
Voltage Circuits
will relieve overload**

The system has a severe interior overload. The operator has initially investigated generation shifting, but this option is not feasible or inadequate to relieve the problem. Next, the operator investigates corrective switching options.

+ Rule218 "(2.1.2.3.3)
(Transmission state interior overload on
contingency action3"
(state transmission state)
(initial result overload)
(location interior)
(next contingency yes)
(next contingency severe yes)
(generation shifting no)

Close

+ Rule244
(state transmission state)
(initial result voltage limit violation on
contingency)

**Voltage
Level**

Close

Appendix C

Normal Event Graphics

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ww3_3.ovg

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ww3_3.ovg

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ww11_9c.ovg

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Rule605b.ovg

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Rule605b.ovg

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Rule608 « Rule608.ovg

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Rule821221 » Text

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Rule832 → Rule831a « Rule831a.ovg

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Rule8323 → Rule831a « Rule831a.ovg

Rule8324 → Rule831a « Rule831a.ovg

Rule8325 → Rule831a « Rule831a.ovg

form name

Requested File
restore.ovd

norm menu (norm evt menu display)	Rule609 "Outline 6.6" (event hydro_scheduling)	Rule821221 "Outline 8.2.2.1" (sa_alarm_cond less_severe)
Rule600 "Outline 6.1" (event economic dispatch)	Rule700 "Outline 7.0" (event corrective_action_study)	Rule830 "Outline 8.3" (event security constrained dispatch)
Rule601 "Outline 6.1.1" (event economic dispatch) (contingency no)	Rule800 "Outline 8.0" (event security_analysis)	Rule831 "Outline 8.3.1" (opf_run_menu display)
Rule602 "Outline 6.1.2" (event economic dispatch) (contingency yes)	Rule820 "Outline 8.2" (sa_alarms_menu display)	Rule832 "Outline 8.3.2" (opf_corrections yes)
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Rule604 "Outline 6.3" (event load_forecasting)	Rule8211 "Outline 8.2.1.1" (sa_alarm_type voltage)	Rule8322 "Outline: 8.3.2.2" (opf_correction transformer_tap_adj)
Rule605 "Outline 6.4" (event purchase_sell_power)	Rule8221 "Outline 8.2.2.1" (sa_alarm_type overload)	Rule8323 "Outline: 8.3.2.3" (opf_correction cap_react_adj)
Rule606 "Outline 6.4" (event purchase_sell_power) (duration one_hour)	Rule82111 "Outline 8.2.1.1.1" (sa_alarm new)	Rule8324 "Outline: 8.3.2.4" (opf_correction interchange_adj)
Rule607 "Outline 6.4" (event purchase_sell_power) (duration more_than_one_hour)	Rule82112 "Outline 8.2.1.1.2" (sa_alarm old)	Rule8325 "Outline: 8.3.2.5" (opf_correction load_shed)
Rule608 "Outline 6.5" (event generator_maintenance)	Rule821222 "Outline 8.2.2.2.2" (sa_alarm_cond more_severe)	

Close

NORMAL POWER SYSTEM OPERATING EVENTS"

1. Economic Dispatch
2. Unit Commitment
3. Load Forecasting"
4. Purchase or Sell Power
5. Generator Maintenance
6. Hydro Scheduling
7. Corrective Action Study
8. Security Analysis
9. Security Constrained Dispatch
- 10.Exit to Main Menu

Close

Close

During normal operating conditions, the operator is required to run an economic dispatch to minimize costs of power system operation. This event occurs every 5 minutes. The status of the power system must be considered in economic operation, therefore, if violations or contingencies are present, it changes the solution technique.

Graphical Solution to Economic Dispatch.

During normal operating conditions, the operator is required to run an economic dispatch to minimize costs of power system operation. This event occurs every 5 minutes. The status of the power system must be considered in economic operation, therefore, if violations or contingencies are present, it changes the solution technique

Rule601 "Outline 6.1.1"
(event economic dispatch)
(contingency no)

Graphical Solution to Economic Dispatch.

The unit commitment program decides which units should be on and off. This calculation is run on a daily basis, usually over a period of 48 to 168 hours ahead.

Recursive Alogrithm

Forward Dynamic Programming

Unit Commitment schedule using shut

- down rule

Rule603 "Outline 6.2"
(event unit commitment)

Close

START

The recursive algorithm to compute the minimum cost in hour

K

with combination I is

$$F_{\text{cos } t}(K, I) = \min_{[L]} [P_{\text{cos } t}(K, I) + S_{\text{cos } t}(K-1, L: K, I) + F_{\text{cos } t}(K-1, L)]$$

where : $F_{\text{cos } t}(K, I)$ = least total cost to arrive at state (K, I)

$P_{\text{cos } t}(K, I)$ = production cost for state (K, I)

$S_{\text{cos } t}(K-1, L: K, I)$ = transition cost from state $(K-1, L)$ to state (K, I)

Close

When contingencies are present

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Close

A load forecast is a valuable piece of information for power system operation. It affects the unit commitment problem, purchases/sales, maintenance, and hydro scheduling. This task is performed daily.

Rule604 "Outline 6.3"
(event load_forecasting)

The purchase/sale of power

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ter
dal
ter

Economic Interference

Area 1

Area 2

Close

Rule605 "Outline 6.4"
(event purchase_sell_power)

Close

The purchase/sale of power is made only if profitable.

Economic Interchange

Rule606 "Outline 6.4"
(event purchase_sell_power)
(duration one_hour)

Close

The purchase/sale of power is made only if profitable.

Rule607 "Outline 6.4"
(event purchase_sell_power)
(duration more_than_one_hour)

HOUR OF WEEK
TYPICAL SUMMER WEEK LOAD PROFILE
SUNDAY - SATURDAY

Close

Generator maintenance schedule is revised at least yearly.

Rule608 "Outline 6.5"
(event generator_maintenance)

Close

Hydro scheduling occurs weekly or monthly.

Typical Hierarchy for Overall
Operations Scheduling

Rule609 "Outline 6.6"
(event hydro_scheduling)

Close

$$\left. \begin{aligned} V_{1j} &= V_{1j-1} + (r_{1j} - q_{1j} - S_{1j})n_j \\ V_{2j} &= V_{2j-1} + (q_{1j} + S_{1j} - S_{2j} - q_{2j})n_j \\ V_{3j} &= V_{3j-1} + (q_{2j} + S_{2j} - S_{3j} - q_{3j})n_j \end{aligned} \right\} \left\{ \begin{array}{l} \text{COUPLED} \\ \text{HYDRAULIC} \\ \text{CONTINUITY} \\ \text{CONSTRAINTS} \end{array} \right\}$$

$$\text{MIN : } \sum n_j F_S(P_{S_j})$$

$$\text{SUB TO : } P_{\text{LOAD}_j} - P_{S_j} - P_{H_{1j}} - P_{H_{2j}} - P_{H_{3j}} = 0$$

Continued

Close

$$\begin{aligned}
L = & \sum_j n_j F_s(P_{s_j}) + \sum_j \lambda_j (P_{LOAD_j} - P_{s_j} - P_{H_{1j}} - P_{H_{1j}} - P_{H_{2j}} - P_{H_{3j}}) \\
& + Y_{1j} (V_{1j} - V_{1j-1} - (r_{1j} - q_{1j} - S_{1j}) n_j) \\
& + Y_{2j} (V_{2j} - V_{2j-1} - (q_{1j} - S_{1j} - S_{2j} - q_{2j}) n_j) \\
& + Y_{3j} (V_{3j} - V_{3j-1} - (q_{2j} - S_{2j} - S_{3j} - q_{3j}) n_j)
\end{aligned}$$

Close

Corrective action programs are used when a known problem exists such as an overloaded line, overloaded transformer, or low bus voltage.

Rule700 "Outline 7.0"
(event corrective_action_study)

Close

Security analysis tests a system with no known overloads.

Contingency Analysis

contingency
definition

translates equipment
oriented contingency list
into network terms

contingency
list

list may be very large

contingency
selection

identifies cases suspected
of violations using
approximate models

cases suspected
of violations

number of cases should be
relatively small

contingency
evaluation

checks for violations using
AC power flow

cases with
violations

types, locations and
severities of violations

Rule800 "Outline 8.0"
(event security_analysis)

Close

Contingency Analysis

translates equipment oriented contingency list into network terms

list may be very large

identifies cases suspected of violations using approximate models

number of cases should be relatively small

checks for violations using AC power flow

types, locations and severities of violations

Rule820 "Outline 8.2"
(sa_alarms_menu display)

Close

classify the security analysis alarm

Contingency Analysis

Rule821 "Outline 8.2.1"
(event security_analysis_alarm)

determine if this is an old or a new alarm

Contingency Analysis

Rule8211 "Outline 8.2.1.1"
(sa_alarm_type voltage)

Close

determine if this is an old or a new alarm

Contingency Analysis

Rule8221 "Outline 8.2.2.1"
(sa_alarm_type overload)

Close

New alarms need a security dispatch run

Contingency Analysis

Rule82111 "Outline 8.2.1.1.1"
(sa_alarm new)

Close

determine if the alarm condition is better or worse

Contingency Analysis

contingency
definition

contingency
list

contingency
selection

cases suspected
of violations

contingency
evaluation

cases with
violations

translates equipment
oriented contingency list
into network terms

list may be very large

identifies cases suspected
of violations using
approximate models

number of cases should be
relatively small

checks for violations using
AC power flow

types, locations and
severities of violations

Rule82112 "Outline 8.2.1.1.2"
(sa_alarm old)

Close

Less sever old alarms just need to be monitored

Rule821221 "Outline 8.2.2.2.1"
(sa_alarm_cond less_severe)

Close

Verify that corrective actions are taking effect

Contingency Analysis

Rule821222 "Outline 8.2.2.2.2"
(sa_alarm_cond more_severe)

Close

Security dispatch is an application program used to achieve a dispatch of generation and other control actions that arm the system against contingencies.

Rule830 "Outline 8.3"
(event security constrained dispatch)

OPF Formulation

Objective:

- minimize a function $f(U,X)$
 - U = control variables
 - X = dependent variables

Equality constraints:

- Power flow equations, including local controls $G(U,X) = 0$

Inequality constraints:

- Limits on controls $U_{min} \leq U \leq U_{max}$
- Functional inequalities $H(U,X) \leq 0$

NOTE:

Except in over-simplified formulations, functions f , G and H are not purely smooth, continuous and analytic, and cannot be handled by standard nonlinear programming methods.

Rule831 "Outline 8.3.1"
(opf_run_menu display)

Close

OPF Formulation

Objective:

- minimize a function $f(U,X)$
 U = control variables
 X = dependent variables

Equality constraints:

- Power flow equations, including
 local controls $G(U,X) = 0$

Inequality constraints:

- Limits on controls $U_{min} \leq U \leq U_{max}$
- Functional inequalities $H(U,X) \leq 0$

NOTE:

Except in over-simplified formulations, functions f , G and H are not purely smooth, continuous and analytic, and cannot be handled by standard nonlinear programming methods.

Rule832 "Outline 8.3.2"
(opf_corrections yes)

Close

The optimal power flow can calculate the generation shifts necessary to achieve changes in power flows necessary to guarantee security of the system. When the generation shifts are calculated the need to be passed to the on line economic dispatch so they will be implemented.

OPF Formulation

Rule8321 "Outline: 8.3.2.1"
(opf_correction generation_shift)

Objective:

- minimize a function $f(U,X)$
 U = control variables
 X = dependent variables

Equality constraints:

- Power flow equations, including
 local controls $G(U,X) = 0$

Inequality constraints:

- Limits on controls $U_{min} \leq U \leq U_{max}$
- Functional inequalities $H(U,X) \leq 0$

NOTE:

Except in over-simplified formulations, functions f , G and H are not purely smooth, continuous and analytic, and cannot be handled by standard nonlinear programming methods.

Cont'd

The optimal power flow can recommend tap adjustments to help guarantee that voltages are within range. To put the recommended tap settings into effect requires the operator to make them individually through the SCADA system.

OPF Formulation

Objective:

- minimize a function $f(U,X)$
 - U = control variables
 - X = dependent variables

Equality constraints:

- Power flow equations, including local controls $G(U,X) = 0$

Inequality constraints:

- Limits on controls $U_{min} \leq U \leq U_{max}$
- Functional inequalities $H(U,X) \leq 0$

NOTE:

Except in over-simplified formulations, functions f , G and H are not purely smooth, continuous and analytic, and cannot be handled by standard nonlinear programming methods.

Cont'd

Rule8322 "Outline: 8.3.2.2"
(opf_correction transformer_tap_adj)

The optimal power flow can recommend capacitor switching adjustments to help guarantee that voltages are within range. To put the recommended capacitor switch settings into effect requires the operator to make them individually through the SCADA system.

OPF Formulation

Rule8323 "Outline: 8.3.2.3"
(opf_correction cap_react_adj)

Objective:

- minimize a function $f(U,X)$
 U = control variables
 X = dependent variables

Equality constraints:

- Power flow equations, including
 local controls $G(U,X) = 0$

Inequality constraints:

- Limits on controls $U_{min} \leq U \leq U_{max}$
- Functional inequalities $H(U,X) \leq 0$

NOTE:

Except in over-simplified formulations, functions f , G and H are not purely smooth, continuous and analytic, and cannot be handled by standard nonlinear programming methods.

Cont'd

Close

The Optimal power flow can recommend that interchange power with a neighbor utility be changed to guarantee the security of the system. In this case the neighbor needs to be consulted so that any changes are coordinated between them. The actual change in interchange is made via the interchange scheduling program which adjusts the economic dispatch and the AGC.

OPF Formulation

Objective:

- minimize a function $f(U,X)$
- U = control variables
- X = dependent variables

Equality constraints:

- Power flow equations, including local controls $G(U,X) = 0$

Inequality constraints:

- Limits on controls $U_{min} \leq U \leq U_{max}$
- Functional inequalities $H(U,X) \leq 0$

NOTE:
Except in over-simplified formulations, functions f , G and H are not purely smooth, continuous and analytic, and cannot be handled by standard nonlinear programming methods.

Cont'd

Rule8324 "Outline: 8.3.2.4"
(opf_correction interchange_adj)

Close

In certain extreme emergencies the optimal power flow will recommend that load be shed. Usually this is in response to a clear danger such as an existing overload or signs that the system is about to go into a voltage collapse. The signals to shed load are sent through the SCADA system.

OPF Formulation

Rule8325 "Outline: 8.3.2.5"
(opf_correction load_shed)

Objective:

- minimize a function $f(U,X)$
 U = control variables
 X = dependent variables

Equality constraints:

- Power flow equations, including
 local controls $G(U,X) = 0$

Inequality constraints:

- Limits on controls $U_{min} \leq U \leq U_{max}$
- Functional inequalities $H(U,X) \leq 0$

Cont'd

NOTE:

Except in over-simplified formulations, functions f , G and H are not purely smooth, continuous and analytic, and cannot be handled by standard nonlinear programming methods.

SLP - Based OPF

Appendix D

Protection Event Graphics

Contents of PROT_EVT.OVD

Prot_evt Menu

Prot_menu Info

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Rule503 « a1_+.ovg

Rule504 « a3_2+.ovg

Rule505 « a3_2+.ovg

Rule506 « Rule506.ovg

Rule507 « Rule507.ovg → 507heat.ovg →

507flux.ovg → 507pressure.ovg →

507active.ovg

Rule508 « a3_29.cht

RuleRp1 « Rulerp1.ovg

RuleRp2 « Rulerp1.ovg

RuleRp2a « Rulerp1.ovg

RuleBp3 « Rulebp3.ovg

RuleBp4 » Text

RuleBp4a « Rulerp1.ovg

RuleBp5 « Rulebp3.ovg + bp5_2.ovg +
bp5_3.ovg

RuleBp6 » Text

RuleBp7 « Rulebp7.ovg + Rulebp7b.ovg

RuleRp8 « Rulerp8.ovg

RuleRp9 « Rulerp1.ovg

RuleRp9a « Rulerp9a.ovg

RuleRp10 « Rulerp10.ovg

RuleRp10a « Rulerp9a.ovg

RuleRp11 » Text

RuleRp12 « Rulerp9a.ovg

RuleRp13 « Rulerp8.ovg

RuleRp14 « Rulerp8.ovg

RuleRp15 « Rulerp8.ovg

(defrule protection menu (prot evt menu display)	Rule506 "Outline 5.2.2.1.2" (event relay action) (another event no)	RuleBp3 "reclose policy" (breaker event breaker failure)	RuleRp9a "reclose policy" (get line voltage)
Rule500 "Outline 5.0" (event relay action)	(weather related no) (relay type impedance)	RuleBp4 "reclose policy" (breaker event hot line work)	RuleRp10a "reclose policy" (jeopardy yes)
Rule501 "Outline 5.1" (event relay action) (another event yes)	Rule507 "Outline 5.2.2.1.3" (event relay action) (another event no)	RuleBp4a "reclose policy" (breaker event reclose failure)	RuleRp11 "reclose policy" (jeopardy no) (or (voltage level 69kv) (voltage level 115kv))
Rule502 "Outline 5.2" (event relay action) (another event no)	(weather related no) (relay type equipment)	RuleBp5 "reclose policy" (breaker event lockout)	RuleRp12 "reclose policy" (jeopardy no) (voltage level 230-500KV)
Rule503 "Outline 5.2.1" (event relay action) (another event no) (weather related yes)	Rule508 "Outline 5.2.2.1.4" (event relay action) (another event no) (weather related no) (relay type fault locating)	RuleBp6 "reclose policy" (breaker event intercompany)	RuleRp13 "reclose policy" (weather good) (load outaged yes)
Rule504 "Outline 5.2.2.1" (event relay action) (another event no) (weather related no)	RuleRp1 "reclose policy rules" (event breaker trips)	RuleBp7 "reclose policy" (breaker event transfer trip)	RuleRp14 "reclose policy" (sectionalized true)
Rule505 "Outline 5.2.2.1.1" (event relay action) (another event no) (weather related no) (relay type differential)	RuleRp2 "reclose policy rules" (auto reclose none)	RuleRp8 "reclose policy" (or (weather good) (weather bad))	RuleRp15 "reclose policy" (sectionalized false)
	RuleRp2a "reclose policy rules" (auto reclose failed)	RuleRp9 "reclose policy" (load outaged no)	Close
		RuleRp10 "reclose policy" (weather bad) (load outaged yes)	

PROTECTION SYSTEM EVENTS"

1. Known Relay Action"
2. Known Breaker Action"
3. Exit to Main Menu"

(prot_evt menu

Close

The operator may only be confronted with a breaker action and will have to determine the relay actions behind it. Otherwise the operator will start at a known relay action.

(protmenu)

13.8 kV SUB. BUS

REV. PWR RELAY

TO LOAD

The system has encountered a protection system failure or malfunction. The operator must first determine if this problem is part of a larger problem within the power system. Typically, protection problems are more frequent when the system has an overload or voltage problem.

Protection Zones

One Line Diagram of a System Showing Primary Protection Zones

Close

Rule500 "Outline 5.0"
(event relay action)

The system has encountered a protection system failure or malfunction. The operator must first determine if this problem is part of a larger problem within the power system. Typically, protection problems are more frequent when the system has an overload or voltage problem. (Rule501)

Close

Rule502 "Outline 5.2"
(event relay action)
(another event no)

Close

If not weather related,
operator must investigate
each possible type of failure.

Differential Relay Connection

Rule504 "Outline 5.2.2.1"
(event relay action)
(another event no)
(weather related no)

Close

Differential Relay Connection

Rule505 "Outline 5.2.2.1.1"
 (event relay action)
 (another event no)
 (weather related no)
 (relay type differential)

Close

Impedance relays tell if a line
experience a fault and where.

(Rule506)

$$\frac{V_R}{I_R} = Z_R$$

$Z_R = (\text{ Impedance seen by relay })$

If Z_R is within the
circle the fault is within
the protection zone and
the relay trips .

Close

Equipment must be inspected since fault was most likely internal to equipment.

Click on boxes for more information. Click in overlay to return.

Incipient Faults

Incipient faults are of three kinds :

Transformer Overheating
Transformer Overfluxing
Transformer Overpressure

Active Faults

Active faults are faults that occur suddenly and require fast action by protective relays.

Close

Rule507 "Outline 5.2.2.1.3"
(event relay action)
(another event no)
(weather related no)
(relay type equipment)

For the most part , these faults are short circuits in the transformer , but other difficulties can also be cited that require prompt action .

(1) Short circuits in wye connected windings .

Grounded through a resistance

Solidly grounded

Ungrounded

(2) Short circuits in delta connected windings .

(3) Phase - to - phase short circuits (in 3 phase transformers)

(4) Turn - to - turn short circuits

(5) Core faults

(6) Tank faults

Overpressure

Overpressure in the transformer tank occurs due to the release of gases or products of combustion that accompany localized heating .

For example , a turn - to - turn fault may burn slowly , releasing gases in the process . Local heating of insulation may give off gases that can accumulate in the sealed transformer tank and cause an increase in pressure .

Overfluxing

A Sudden loss of load on an isolated portion of the system can cause the voltage to rise . This condition can cause overfluxing of the transformer and an increase in stress on the winding insulation . Continued periods of overfluxing may lead to insulation breakdown of the magnetic circuit insulating materials .

Overheating :

Overheating may be due to several different internal transformer conditions , as follows :

- (1) Poor internal connections , in either the electric or the magnetic circuits .**
- (2) Loss of coolant due to leakage .**
- (3) Blockage of coolant flow .**
- (4) Loss of fans or pumps that are designed to provide cooling .**

If fault locating relay gives wrong indication this must be corrected.

When a breaker trips, there is the possibility of automatic reclosing wherein the breaker stays open for a short time and then is reclosed. If the fault that cause the original trip has disappeared, the line is back in service quickly. If reclosing is unsuccessful there is a more serious problem to be investigated.

Pre Fault

Fault Strikes

**Breakers Open
Fault Clears**

**Breakers Reclose
Automatically**

RuleRp1 "reclose policy rules"
(event breaker trips)

Close

When there is no automatic reclosing, the operator needs to determine the reason for the failure to reclose before taking any other actions.

Pre Fault

Fault Strikes

**Breakers Open
Fault Clears**

Breakers Reclose Automatically

RuleRp2 "reclose policy rules"
(auto reclose none)

Close

In bad weather, there are often lightning strikes that cause trips. If these trip fail to reclose it may be because the resulting arc was not extinguished at the time the breaker reclosed. Often the operator will simply reclose manually. If good weather, there is need for further investigation before reclosing manually.

Pre Fault

Fault Strikes

**Breakers Open
Fault Clears**

**Breakers Reclose
Automatically**

RuleRp2a "reclose policy rules"
(auto reclose failed)

A breaker can fail resulting in an internal fault or in an inability to change state at all. In this case the breaker must be isolated using sectionalizing switches and then investigated by service crews before being placed back in service.

Disconnect Switches are used to isolate Breaker for repair. Disconnects are manually operated by maintenance personnel.

RuleBp3 "reclose policy"
(breaker event breaker failure)

Close

Occasionally the field crews will want to work on a transmission line while it is hot (energized) and they will throw the relay protecting that line over to manual.

**RuleBp4 "reclose policy"
(breaker event hot line work)**

Close

Reclose of the breaker through the SCADA system is the first step to see if the line has been cleared of a fault. If it works, little else is done, if not, the line must be inspected.

Pre Fault

Fault Strikes

**Breakers Open
Fault Clears**

**Breakers Reclose
Automatically**

Close

RuleBp4a "reclose policy"
(breaker event reclose failure)

A breaker lockout occurs when the relay system or the breaker trip system detects a problem with the breaker and sets it to "lockout" so that it cannot be tripped with the lockout circuit being manually reset after substation personnel manually inspect the breaker.

RuleBps reclose policy
(breaker event lockout)

Opening a line to another company must be coordinated with that company since it may affect flows into or out of that company, or the voltages on buses near the line terminals.

**RuleBp6 "reclose policy"
(breaker event intercompany)**

Close

A transfer trip signal was detected by the relay. The transfer trip is designed to cause a trip of a line segment which was detected by a relay at the other end of the line. The line cannot be reclosed if the transfer trip signal is present since there may still be a fault at the other end.

RuleBp7 "reclose policy"
(breaker event transfer trip)

General View of a Pilot Protection System

If load has been taken out by a breaker action, this will change the priority of the actions in the investigation. Operators may opt to do a "work around" to get the load back on first.

RuleRp8 "reclose policy"
(or (weather good)
(weather bad))

The need for load restoration is eliminated and the operators can go after the line problem by patrolling it looking for problems such as fallen trees, etc.

RuleRp9 "reclose policy"
(load outaged no)

Pre Fault

Fault Strikes

**Breakers Open
Fault Clears**

**Breakers Reclose
Automatically**

RuleRp9a "reclose policy"
(get line voltage)

RuleRp10 "reclose policy"
(weather bad)
(load outaged yes)

Close

Step Time and Impedance Zones for Distance Relays

Continued

Close

Close

Classification of Pilot Relaying Schemes

Classification	Common Choices
Comparison Method	Direction Comparison Phase Comparison
Selectivity Method	Under Reaching Over Reaching
Tripping Logic	Transfer Trip Blocking
Security Logic	Direct Permissive Redundant

RuleRp10a "reclose policy"
(jeopardy yes)

Close

Manual reclose at lower voltages is less risk for the entire system and will be done quickly.

**RuleRp11 "reclose policy"
(jeopardy no)
(or (volt level 69kv)
(volt level 115kv))**

Close

RuleRp12 "reclose policy"
(jeopardy no)
(volt level 230-500KV)

Close

The utmost care must be
ta
th
in

RuleRp13 "reclose policy"
(weather good)
(load outaged yes)

If the suspect faulty equipment is sectionalized out, i.e. it has been completely disconnected, then reclosing can proceed

RuleRp14 "reclose policy"
(sectionalized true)

Sometimes a complete

se
th
co
ex

RuleRp15 "reclose policy"
(sectionalized false)

Appendix E

Control Event Graphics

Contents of CTRL_EVT

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Rule302 « 195b.ovg + diode.ovg

Rule303 « 195b.ovg + diode.ovg

Rule304A « 195b.ovg + diode.ovg

Rule304 « 195b.ovg + diode.ovg

Rule305 « 195b.ovg + diode.ovg

Rule306 « 195b.ovg + diode.ovg

Rule307 « 195b.ovg + diode.ovg

Rule308a « 195b.ovg + diode.ovg

Rule308 « 195b.ovg + diode.ovg

Rule309 « 195b.ovg + diode.ovg

Rule310 « 195b.ovg + diode.ovg

Rule311 « 195b.ovg + diode.ovg

control menu (ctrl evt menu display)	Rule306 "Outline 3.3.3" (event computer failure) (initial result partial failure)	
Rule300 "Outline 3.1" (event rtu failure)		
Rule301 "Outline 3.2" (event communications failure) (system-data num failed rtus ?num)	Rule307 "Outline 3.3.4" (event software failure)	
Rule302 "Outline 3.2.1" (event communications failure) (rtus down one)	Rule308A "Outline 3.4" (event power failure)	
Rule303 "Outline 3.2.2" (event communications failure) (rtus down several)	Rule308 "Outline 3.4.1" (event power failure) (initial result outside power supply failure)	
Rule304A "Outline 3.3" (event computer failure)	Rule309 "Outline 3.4.2" (event power failure) (initial result permanent failure)	
Rule304 "Outline 3.3.1" (event computer failure) (initial result primary down backup operating)	Rule310 "Outline 3.4.3" (event power failure) (initial result UPS successful)	
Rule305 "Outline 3.3.2" (event computer failure) (initial result permanent failure)	Rule311 "Outline 3.4.4" (event power failure) (initial result UPS fails)	
		Close

The control system consists of the remote terminal units in substations, the communications links to the RTU's and to other computer systems, the computer system, its software and the power supplies at the computer center.

The remote terminal unit (rtu) has some problem. An rtu is part of the information and communication network of the system. If an rtu fails, some information may be lost. Since this information supplies relay and protection information, the safety of system equipment may be reduced. Therefore, the operator should establish the severity of the failure and how critical the information from this unit(s) is for system security.

The operator has experienced failure in the communications network. The number of remote terminal units involved is critical to establish the extent of the problem and the quickness of required actions.

One rtu is the source of the problem. The operator should discuss the problem with the communications department. This does not appear to be critical, so the time frame of action is relaxed.

The operator has discovered several rtu's have failed. The operator should contact the communications department immediately. With this much information lost, the operator may be crippled in his knowledge about the system state and, if problem would arise, the operator would have a more difficult time managing the problem. Hence, this is a problem requiring immediate attention and swift correction.

The failure of the computer system necessitates a repair so as to guarantee continued operation of the control system. If the primary is down and the backup operating the primary must be repaired as soon as possible. If the entire system is down, the operation must be taken by a remote backup system.

The primary computer system has failed, but the backup system is operating adequately. The operator should order work on the primary unit as soon as possible. If there is a problem with the backup, the operator has lost computer control of the system. This would be a severe problem.

The system operator has lost the primary computer and, therefore, has lost most of the control functions. The operator should dispatch crews to critical substations and operating points in the system. Communication channels should be opened between the control center, substations, and generating facilities. Work on the failure should be requested immediately.

The computer system has a partial failure. The operator should devise a plan to work around the failure and request maintenance.

Operating systems and application software will occasionally reach a point of failure. Rebooting the system may take time. The operator will report this, so the problem can be traced and fixed.

If there is a failure of the outside power source, the local distribution system maintenance crew will be called. If the failure is permanent the operators must decide to wait and operate with the UPS (if operting) or to shift to a remote operations backup system.

The operator has loss power to the operating center. The operator should immediately verify that the uninterruptible power supply (UPS) has functioned properly and establish the current status of the generators. (Why did the power fail? Local to the control center or is there a system wide problem?)

Rule308 "Outline 3.4.1"
(event power failure)
(initial result outside power supply failure)

The operator is experiencing a loss of power to the operating center. This reduces the amount of control and information the operator has. Therefore, the operator should dispatch crews to critical substations and open communication links with other operating centers, substations, and generating plants.

The UPS system has functioned properly, so the operator should monitor its status. Immediately, the operator should identify the source of the failure in the power supply and request maintenance now.

Even with a UPS, a standby generator is usually provided to backup the system. When started the computer system can be brought on line.

Appendix F

Restoration Event Graphics

Contents of RESTORE.OVD:

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Restoraton Menu

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Rule417c » Text

Rule418 « Rule417a.ovg

Rule419 « Rule417a.ovg

Rule420 « Rule417a.ovg

Restoration Menu	+Rule405 "Outline 4.1.3.1.1" (state restoration state) (initial result restoration required) (out of service transmission) (equipment out transmission line)	+ Rule410 "Outline 4.1.3.2.3" (state restoration state) (initial result restoration required) (out of service transmission) (equipment out transformer) (source of outage unknown)	
Rule400 "Outline 4.1" (state restoration state) (initial result restoration required)	+ Rule406 "Outline 4.1.3.1.2" (state restoration state) (initial result restoration required) (out of service transmission) (equipment out transmission line) (source of outage known)	+ Rule411 "Outline 4.1.3.3.1" (state restoration state) (initial result restoration required) (out of service transmission) (equipment out substation)	
+Rule401 "Outline 4.1.2" (state restoration state) (out of service load) (system-data load restore min ?min)	+Rule407 "Outline 4.1.3.1.3" (state restoration state) (initial result restoration required) (out of service transmission) (equipment out transmission line) (source of outage unknown)	+ Rule412 "Outline 4.1.3.3.2" (state restoration state) (initial result restoration required) (out of service transmission) (equipment out substation) (source of outage known)	
+Rule402 "Outline 4.1.2.2.1" (state restoration state) (out of service load) (gen reserve reg yes)	+Rule408 "Outline 4.1.3.2.1" (state restoration state) (initial result restoration required) (out of service transmission) (equipment out transformer)	+Rule413 "4.1.3.3.3" (state restoration state) (initial result restoration required) (out of service transmission) (equipment out substation) (source of outage unknown)	
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+Rule415 "4.1.3.4.2" (state restoration state) (Initial result restoration required) (out of service transmission) (equipment out underground cables) (source of outage known)	+Rule418 "Outline 4.1.5" (state restoration state) (Initial result restoration required) (generation type predominantly thermal)	
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Rule417 "Outline 4.1.4.1" (state restoration state) (Initial result restoration required) (out of service complete blackout)	+ Rule420 "Outline 4.1.7" (state restoration state) (Initial result restoration required) (generation type predominantly hydro)	
+Rule417A "Outline 4.1.4.1" (state restoration state) (Initial result restoration required) (out of service generation)		
+Rule417B "Outline 4.1.4.1" (state restoration state) (Initial result restoration required) (out of service load transmission)		

"RESTORATION MENU"

What is the extent of the outage?"

- 1. Load"**
- 2. Transmission"**
- 3. Generation"**
- 4. Load_transmission"**
- 5. Load_transmission_generation"**
- 6. Complete_blackout"**
- 7. Exit to Main Menu"**

Close

The system has entered a restoration state. Some components of normal system operations have been lost. The system operator must establish what has been lost; load, transmission, or generation or any combination of the three. The amount of losses determines what steps the operator must take to restore service, so this is the first step of the restoration procedure.

Rule400 "Outline 4.1"
(state restoration state)
(Initial result restoration required)

Close

The operator must determine the amount of load to be restored. If load was out for a long time the cold load pick up could be up to 250% of the original lost. In this restoration state, the only loss was load. The normal generation and transmission facilities are still operational. Therefore, the operator must supply power to the unserved load. The operator must establish how much load was lost, how much can be brought up immediately, and when total restoration will occur. After knowing how much was lost, the operator can evaluate the current reserves to determine what load can be restored immediately.

Rule401 "Outline 4.1.2"
(state restoration state)
(out of service load)
(system-data load restore min ?min)

The current reserves are sufficient to meet
the
a
s
s
w
e
f

+Rule402 "Outline 4.1.2.2.1"
(state restoration state)
(out of service load)
(gen reserve reg yes)

The current spinning reserves are not enough to

m
se
ge
wo
op
ne

+Rule403 "Outline 4.1.2.2.2"
(state restoration state)
(initial result restoration required)
(out of service load)
(gen reserve reg no)

The operator has discovered that the

lost
tran
mu
con
sys
tran
sub

**Any fault on the transmission
system must be removed
before reclosing.**

Close

+Rule404 "Outline 4.1.3"
(state restoration state)
(initial result restoration required)
(out of service transmission)

Fault must be removed before reclosing.

Determine the cause of the outage. Begin, by looking at the status of relays and breakers. Did auto-reclose fail? The source of the outage in the transmission network has been discovered to be a transmission line. The operator must determine what caused the outage of the line. Some indication of the sequence of events leading up to the outage can be determined from the relays and breakers. The relays and breakers will inform the operator if auto-reclose was attempted. (How many times was reclose attempted? Are the breakers locked out? Is there a failure in the protection system? Is the line down?)

+Rule405 "Outline 4.1.3.1.1"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out transmission line)

Close

What are some different causes? Fault, downed line, lightning, weather, wind, snow, ice, failure in protection.

Co

Fault must be removed before reclosing.

+ Rule406 "Outline 4.1.3.1.2"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out transmission line)
(source of outage known)

Close

What are some different causes? Fault, downed line, lightning, weather, wind, snow, ice, failure in protection. Could the

Fault must be removed before reclosing.

+Rule407 "Outline 4.1.3.1.3"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out transmission line)
(source of outage unknown)

Close

The operator must first determine the cause of the outage by looking at relays and substation control room display. The outage in the transmission network has been discovered to be a transformer. The operator must first determine what was the source of the transformer loss. Some indication can be obtained from the transformer protection relays and the control room instruments. The source of the outage must be found before any reclose on the transformer is attempted. The short circuit currents and probability for damage are not worth risking. Replacing or repairing a transformer is costly in time and money, so precautions must be taken to prevent damage.

+Rule408 "Outline 4.1.3.2.1"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out transformer)

Close

Outage of transformer could be due to internal cause or external cause. If problem were external to transformer, then it can be caused by external fault. If problem were internal to transformer, then it can be caused by internal fault.

+Rule409 "Outline 4.1.3.2.2"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out transformer)
(source of outage known)

Close

Operator's only option is to send crew to determine cause of outage.

+ Rule410 "Outline 4.1.3.2.3"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out transformer)
(source of outage unknown)

Close

The operator must first determine the cause of the outage by looking at relays and substation control room display. If differential relay action occurred, send an inspection crew. The source of the transmission network outage was discovered to be a substation. The operator should find the direct cause of the substation outage, before any reclose is attempted. The short circuit currents on a bus fault would be large and can throw the system off of security.

+ Rule411 "Outline 4.1.3.3.1"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out substation)

Close

If outage cause is known, then isolate affected component and reclose remainder of substation. Send crew to repair or determine the usefulness of isolated equipment.

+ Rule412 "Outline 4.1.3.3.2"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out substation)
(source of outage known)

Close

What are some causes? What would be the time frame for requesting actions?

+Rule413 "4.1.3.3"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out substation)
(source of outage unknown)

Close

The operator must first determine the cause of the outage by looking at relays. The source of the transmission network outage was discovered to be an underground cable. Underground cables require special attention during restoration. The reactive power supply can be a problem due to heavy charging capacitance in the cables.

**Fault must be removed before
reclosing on cable**

+Rule414 "Outline 4.1.3.4.1"
(state restoration state)
(Initial result restoration required)
(out of service transmission)
(equipment out underground cables)

Close

**Fault must be removed before
reclosing on cable**

What are some typical causes of underground cable

o
fo

+Rule415 "4.1.3.4.2"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out underground cables)
(source of outage known)

Close

What are some typical causes of underground cable outages? How often are they inspected and how are faults found?

+Rule416 "Outline 4.1.3.4.3"
(state restoration state)
(initial result restoration required)
(out of service transmission)
(equipment out underground cables)
(source of outage unknown)

**Fault must be removed before
reclosing on cable**

Close

Some parts of the system have experienced a blackout. The operator proceeds with a restoration procedure defined by the type of generating plants located within the power system.

Rule417 "Outline 4.1.4.1"
(state restoration state)
(initial result restoration required)
(out of service complete blackout)

Close

Some parts of the system have experienced a

+Rule417A "Outline 4.1.4.1"
(state restoration state)
(initial result restoration required)
(out of service generation)

**Thermal: Slow
to restore to
full output.**

**Hydro: Quick
to restore to
full output.**

Close

Some parts of the system have

**Thermal: Slow
to restore to
full output.**

**Hydro: Quick
to restore to
full output.**

+Rule417B "Outline 4.1.4.1"
(state restoration state)
(initial result restoration required)
(out of service load transmission)

Close

Some parts of the system have experienced a blackout. The operator proceeds with a restoration procedure defined by the type of generating plants located within the power system.

Rule417C "Outline 4.1.4.1"
(state restoration state)
(initial result restoration required)
(out of service load transmission generation)

Close

Sectionalization of the system into two or more subsystems and simultaneous reintegration of generation and transmission in each subsystem. Selection of subsystems is based on black-start capability within each subsystem and steam generators with hot start capability, and any transmission and loads required to interconnect them. Division of the restoration procedure into restart, reintegration, load pick-up and interconnection phases. During restart conditions, the operator should be aware of protective relays which could initiate an undesirable regulator response or generator trip. Some of the relays are:

- a. Volts per Hertz - this relay will operate if this ratio becomes excessive (volts too high or frequency too low). Some voltage regulators automatically alter the voltage setpoint for changes in frequency.
- b. Out-of Step, Under-Excitation, Distance- relays are impedance type relays and could operate during short electrical power swings or transients.
- c. Frequency - relay monitors electrical frequency and could operate before turbine speed protection.
- d. Field Forcing - relay will not trip the unit but will establish full field flow during periods of low voltage. Some field rheostats are changed to a new full field position by this relay.

**Thermal: Slow
to restore to
full output.**

**Hydro: Quick
to restore to
full output.**

+Rule418 "Outline 4.1.5"
(state restoration state)
(initial result restoration required)
(generation type predominantly thermal)

Close

The system restoration plan developed for hydro thermal systems is based on energizing the entire bulk power transmission system in one step and providing station service to all thermal generating stations. This approach uses the ability of large hydro stations to absorb the charging currents of the complete transmission system. It is an attempt to avoid the time consuming line sectionalization and switching operations which are normally required in system restoration. Division of the restoration procedure into restart, reintegration, load pick-up and interconnection phases. The restart phase begins with providing station service for the restart of steam units from hydro units. The high voltages at the receiving end of the lines are avoided by manual operation of hydro's voltage regulators far below normal. During restart conditions, the operator should be aware of protective relays which could initiate an undesirable regulator response or generator trip. Some of the relays are:

a. Volts per Hertz - this relay will operate if this ratio becomes excessive (volts too high or frequency too low). Some voltage regulators automatically alter the voltage setpoint for changes in frequency.

b. Out-of Step, Under-Excitation, Distance - relays are impedance type relays and could operate during short electrical power swings or transients.

c. Frequency - relay monitors electrical frequency and could operate before turbine speed protection.

d. Field Forcing - relay will not trip the unit but will establish full field flow during periods of low voltage. Some field rheostats are changed to a new full field position by this relay.

**Thermal: Slow
to restore to
full output.**

**Hydro: Quick
to restore to
full output.**

+Rule419 "Outline 4.1.6"
(state restoration state)
(initial result restoration required)
(generation type hydro thermal mix)

Close

The system restoration plan developed for all hydro or primarily hydro systems emphasize the switching operation and the response of prime movers to a sudden load pickup. In this plan, due consideration is given to the time it takes to isolate and energize the necessary lines by using central control systems to execute the switching operation programs. The off-line dynamic programs are used to determine responses of the system and provide guidelines for load pick-up based on the prevailing generation on line, transmission configuration and system loading. Division of the restoration procedure into restart, reintegration, load pick up and interconnection phases. The restart phase begins with providing station service for the any other units from hydro units. The high voltages at the receiving end of the lines are avoided by manual operation of hydro's voltage regulators far below normal. During restart conditions, the operator should be aware of protective relays which could initiate an undesirable regulator response or generator trip. Some of the relays are:

- a. Volts per Hertz - this relay will operate if this ratio becomes excessive (volts too high or frequency too low). Some voltage regulators automatically alter the voltage setpoint for changes in frequency.
- b. Out-of Step, Under-Excitation, Distance - relays are impedance type relays and could operate during short electrical power swings or transients.
- c. Frequency - relay monitors electrical frequency and could operate before turbine speed protection.
- d. Field Forcing - relay will not trip the unit but will establish full field flow during periods of low voltage. Some field rheostats are changed to a new full field position by this relay.

**Thermal: Slow
to restore to
full output.**

**Hydro: Quick
to restore to
full output.**

+ Rule420 "Outline 4.1.7"
(state restoration state)
(initial result restoration required)
(generation type predominantly hydro)

Close